Section

M

An Overview of Ground Water Quality in Ohio

M1. Introduction

Section M summarizes water quality assessment data for Ohio's major aquifers based on information requested in the 2006 Integrated Reports Guidance and the 1997 Guidelines for Preparation of the Comprehensive State Water Quality Assessments.

Ground water protection programs for Ohio are briefly summarized in Section M2 as required by section 106(e) of the Clean Water Act. Programs to monitor, evaluate, and protect ground water resources are implemented by various state, federal, and local agencies. Ohio EPA is the designated agency for monitoring and evaluating ground water quality and assessing ground water contamination problems. Within Ohio EPA, the Division of Drinking and Ground Waters (DDAGW) carries out these functions, and coordinates various ground water monitoring efforts within the agency and with other state programs through the Ohio Water Resources Council and the State Coordinating Committee on Ground Water. Short program descriptions are provided with links to program-based web pages to provide the most current information.

Ohio's three major aquifer types are described in Section M3. Where possible, the water quality data are associated with major aquifer types. The aquifer descriptions allow the reader to associate water quality with geologic settings.

Sections M4 and M5 summarize sites with verified ground water contamination and identify the major nonpoint sources of ground water contamination in Ohio. These data were obtained from various sources including:

- Ground Water Impacts Database (maintained by Ohio EPA - DDAGW);
- Potential contaminant sources inventoried as part of Ohio EPA – DDAGW's Source Water Assessment and Protection Program (SWAP);
- Underground injection control sites identified in Ohio EPA – DDAGW and Ohio Department of Natural Resources (ODNR) – Division of Mineral Resource Management (DMRM) databases;
- Leaking and formerly leaking underground storage tanks from Ohio Department of Commerce – Division of Fire Marshal's Bureau of Underground Storage Tank Regulations (BUSTR) databases; and
- Federal databases listing Department of Development/Department of Energy (DOD/DOE) facilities and National Priorities List/Comprehensive Environmental Response, Compensation, and Liability Act (NPL/CERCLA) sites.

In many instances, these data are not associated with the geologic setting of the impacted aquifer, so statewide summaries are provided.

Section M6 summarizes ground water quality impairments by parameter within Ohio's major aquifers. Two primary data sets are used in this analysis: the drinking water compliance data for public water systems (PWSs); and the ambient ground water quality data. The PWS compliance data represents treated (post-processing) water distributed to the public. The Ambient Ground Water Quality Monitoring Program (AGWQMP) is the Ohio EPA - DDAGW program created to monitor "raw" (untreated) ground water. The goal is to collect, maintain, and analyze raw ground water quality data to measure long-term changes in the water quality of major aquifer systems. Since Ohio does not have statewide ground water quality standards, comparisons to primary maximum contaminant levels (MCL) or secondary maximum contaminant levels (SMCL) for drinking water were used.

Section M7 briefly discusses ground water-surface water interaction (GW-SW) and a few special studies that provide insight on the interaction, which lead to suggestions for future ground water monitoring efforts. Section M8 presents conclusions and recommendations for future direction concerning statewide ground water monitoring and protection of Ohio's major aquifers.

M2. Ohio's Ground Water Programs

Ohio Water Resources Council - On July 1, 2001, Governor Bob Taft established a permanent Ohio Water Resources Council (OWRC) with the mission: Guide the development and implementation of a dynamic process to advance the management of Ohio's water resources. The State Agency Coordination Group, with representatives from the state agencies dealing with water issues, was also established to serve as a technical resource for the OWRC. The current 10-year vision and four year action plan focuses on water resources in the following areas: Education and Outreach, Watershed Management, Water Quality, Water Quantity, Data and Information, Water Resource Infrastructure, and Water-Related Natural Hazards. The action Items for 2010-2014 are listed on the web site at: http://www.dnr.state.oh.us/tabid/15378/default.aspx.

State Coordinating Committee on Ground Water - The State Coordinating Committee on Ground Water (SCCGW) was created in 1992 by the directors of the state agencies that have ground water program responsibilities. The purpose is to promote and guide the implementation of coordinated, comprehensive, and effective ground water protection and management programs for Ohio. The SCCGW used the OWRC's four-year action plan to outline SCCGW priorities. Details on the SCCGW priority actions for data and information, education and outreach, watershed management, water quality, water quantity, water resource infrastructure, and water-related natural hazards are provided in the priorities section of the SCCGW Web site. http://wwwapp.epa.ohio.gov/ddagw/SCCGW/

Ohio Ground Water Protection Programs - Programs to monitor, evaluate, and protect ground water resources in Ohio are administered by federal, state and local agencies. The Ohio EPA is the designated state ground water quality management agency. The ODNR - Division of Water is responsible for evaluation of the quantity of ground water resources. Ground water-related activities at the state level are also conducted by the Ohio Departments of Agriculture, Commerce (Division of State Fire Marshal), Health, and Transportation. The United States Geological Survey (USGS), Ohio Water Science Center, contributes to these efforts with water resource research. Table M-1 (based on Table 5-2, U.S. EPA 305(b) Guidelines, 1997) summarizes agencies responsible for administering the various ground water programs in Ohio.

Table M-1. Summary of Ohio ground water protection programs.

Programs or Activities	Check (✓)	Implementation Status	Responsible State Agency
Active SARA Title III Program	✓	E	OEPA - DERR
Ambient ground water monitoring system	✓	E	OEPA - DDAGW
Aquifer vulnerability assessment	✓	CE	ODNR – DSWR OEPA – DDAGW
Aquifer mapping	✓	CE	ODNR – DSWR OEPA – DDAGW
Aquifer characterization	✓	CE	ODNR – DSWR
Comprehensive data management system	✓	UR [a]	OWRC
Consolidated Cleanup Standards	NA		
Ground water Best Management Practices	✓	E	ODNR, ODA
Ground water legislation	✓	UR [b]	All Agencies
Ground water classification	✓	E [c]	OEPA, ODNR
Ground water quality standards (program specific)	✓	E [d]	OEPA
Interagency coordination for ground water protection initiatives	✓	E	OWRC, SCCGW
Nonpoint source controls	✓	CE	ODA, OEPA, ODNR
Pesticide State Management Plan	✓	E [e]	ODA
Pollution Prevention Program	✓	E	OEPA - OCAPP
Resource Conservation and Recovery Act (RCRA) Primacy	✓	E	OEPA - DMWM
Source Water Assessment Program	✓	E	OEPA - DDAGW
State Property Clean-up Programs	✓	E	OEPA - DERR
Susceptibility assessment for drinking water/wellhead protection	✓	E	OEPA
State septic system regulations	✓	UR [f]	ODH, OEPA
Underground storage tank installation requirements	✓	E	SFM/BUSTR
Underground Storage Tank Remediation Fund	✓	E [g]	SFM/BUSTR
Underground Storage Tank Permit Program	✓	E	SFM/BUSTR
Underground Injection Control Program	✓	E [h]	OEPA – DDAGW ODNR – DMRM
Well abandonment regulations	✓	E [i]	ODNR, OEPA DDAGW, ODH
Wellhead Protection Program (EPA-approved)	✓	E [j]	OEPA
Well installation regulations	✓	E [k]	OEPA, ODH

Table Notes: **E** – Established; **CE** - Continuing Effort; **UD** - Under Development; **UR** - Under Revision

[a] Data management occurring on an agency level. A web-based ground water metadata site was developed to provide links to ground water quality data in Ohio and OWRC proposed expanding this site to develop an Ohio Water Information Gateway. It appears, however, improvements in search engines make this effort unnecessary.

[b] Rules are required to be reviewed every 5 years by state statute.

[c] Established through program-specific classifications.
[d] Standards are program-specific.
[e] ODA received cooperative commitment from other Ohio agencies for the Generic Pesticide Management Plan. The requirement for Specific Pesticide Management Plan was dropped.
[f] The 2nd DRAFT of the proposed Household Sewage Treatment Systems Rules was released for comment in November 2013. The draft sewage treatment system rules (Ohio Administrative Code 3701-29) can be accessed on the ODH website at: http://www.odh.ohio.gov/rules/drafts/drafts.aspx
Comments will be accepted until December 12, 2013. The Ohio Public Health Advisory Board will address the comments before the rules are moved forward for adoption. ODH is proposing the rescission of the current Ohio Administrative Code Chapter 3701-29 and replacing this chapter with the new proposed household sewage treatment systems rules. It is anticipated that the draft rules will become effective in April or May 2014. Larger systems are regulated by Ohio EPA under separate regulations.
[g] Remediation funds are available from the Petroleum Underground Storage Tank Release Compensation Fund.
[h] Ohio EPA regulates Class I and V injection wells; ODNR regulates Class II and III injection wells.
[i] Technical Guidance for Sealing Unused Wells prepared by SCCGW (1996 being revised in 2013-1014).
[j] Wellhead Protection Program has evolved to the Source Water Protection Program.
[k] Technical Guidance for Well Construction and Ground Water Protection prepared by SCCGW (2000). Ohio EPA new wells workgroup has revised requirements for approving new PWS wells that incorporate elements of the Source Water Protection Program and water quality into the well approval process.

Program Web Sites:

ODA - Ohio Department of Agriculture

Pesticide and Fertilizer Regulation Program

http://www.agri.ohio.gov/apps/odaprs/pestfert-prs-index.aspx

Livestock Environmental Permitting Program

http://www.agri.ohio.gov/divs/dlep/dlep.aspx

ODH - Ohio Department of Health

Private Water Systems

http://www.odh.ohio.gov/odhprograms/eh/water/PrivateWaterSystems/main.aspx

Sewage Treatment Systems Program

http://www.odh.ohio.gov/odhPrograms/eh/sewage/sewage1.aspx

ODNR - Ohio Department of Natural Resources

http://www2.ohiodnr.gov/

Division of Soil and Water Resources

http://ohiodnr.com/tabid/21817/Default.aspx

Division of Mineral Resources Management

http://ohiodnr.com/mineral/tabid/10352/Default.aspx

Division of Oil and Gas Resources

http://oilandgas.ohiodnr.gov/

Division of Geologic Survey

http://ohiodnr.com/geosurvey/default/tabid/7105/default.aspx

Ohio EPA - Ohio Environmental Protection Agency

http://www.epa.ohio.gov/

Division of Drinking and Ground Waters

http://www.epa.ohio.gov/ddagw/

Division of Surface Water

http://www.epa.ohio.gov/dsw/

Office of Compliance Assistance and Pollution Prevention

http://www.epa.ohio.gov/ocapp/

Division of Environmental Response and Revitalization
http://www.epa.ohio.gov/derr/
Division of Materials and Waste Management
http://www.epa.ohio.gov/dmwm/

OWRC – Ohio Water Resource Council
http://www.ohiodnr.com/tabid/15378/default.aspx

SCCGW – State Coordinating Committee on Ground Water
http://wwwapp.epa.ohio.gov/ddagw/SCCGW/

SFM/BUSTR – State Fire Marshall/ Bureau of Underground Storage Tank Regulations
http://www.com.ohio.gov/fire/

M3. Ohio's Major Aquifers

Ohio has abundant surface and ground water resources. Average rainfall ranges between 30 to 44 inches a year (increasing from northwest to southeast), which drives healthy stream flows. Infiltration of a small portion of this rainfall (3-16 inches) recharges the aquifers and keeps the streams flowing between rains. Ohio's aquifers can be divided into three major types as illustrated in Figure M-1. The sand and gravel buried valley aquifers (in blue) are distributed through the state. The valleys filled by these sands and gravels are cut into sandstone and shale in the eastern half of the state (in tans) and into carbonate aquifers (in greens) in the western half. The sandstone and carbonate aquifers generally provide sufficient production for water wells except where dominated by shale, as in southwest and southeast Ohio.

Sand and Gravel Aquifers - The unconsolidated sand and gravel units, typically associated with buried valley aquifer systems, are Ohio's most productive water-bearing formations or aquifers. These valleys were cut into the bedrock by pre-glacial and glacial streams and, subsequently, the valleys were back-filled with deposits of sand, gravel and other glacial drift by glacial and alluvial processes as the glaciers advanced and receded. Buried valley aquifers are found beneath and adjacent to the Ohio River, its major tributaries, and other pre-glacial stream channels such as the Teays River. The distribution of these Quaternary sand and gravel units is presented as thin bands of blue in Figure M-1 (modified from ODNR Glacial Aquifer Maps, 2000). In addition to the buried valley aquifers, several other types of productive sand and gravel aquifers are included in Figure M-1. In the northwest corner of the state, the triangular area of sand and gravel units bordering Michigan and Indiana includes sheets of outwash or sand and gravel that occur between sheets of glacial till. Present day stream processes deposit alluvial sand and gravel deposits that also serve as aquifers. Other geologic settings included in the sand and gravel aquifers are the outwash/kame and beach ridge deposits, including the Oak Opening Sands (large patches of sand and gravel in northwest Ohio).

Water production from the coarser-grained and thicker sand and gravel deposits ranges up to 500 to 1,000 gallons per minute (gpm). Lower yields from sand and gravel aquifers are more common. The production rate depends on the type, distribution, permeability, and thickness of permeable glacial/alluvial deposits and well construction parameters, such as well diameter, length of well screen, and well development.

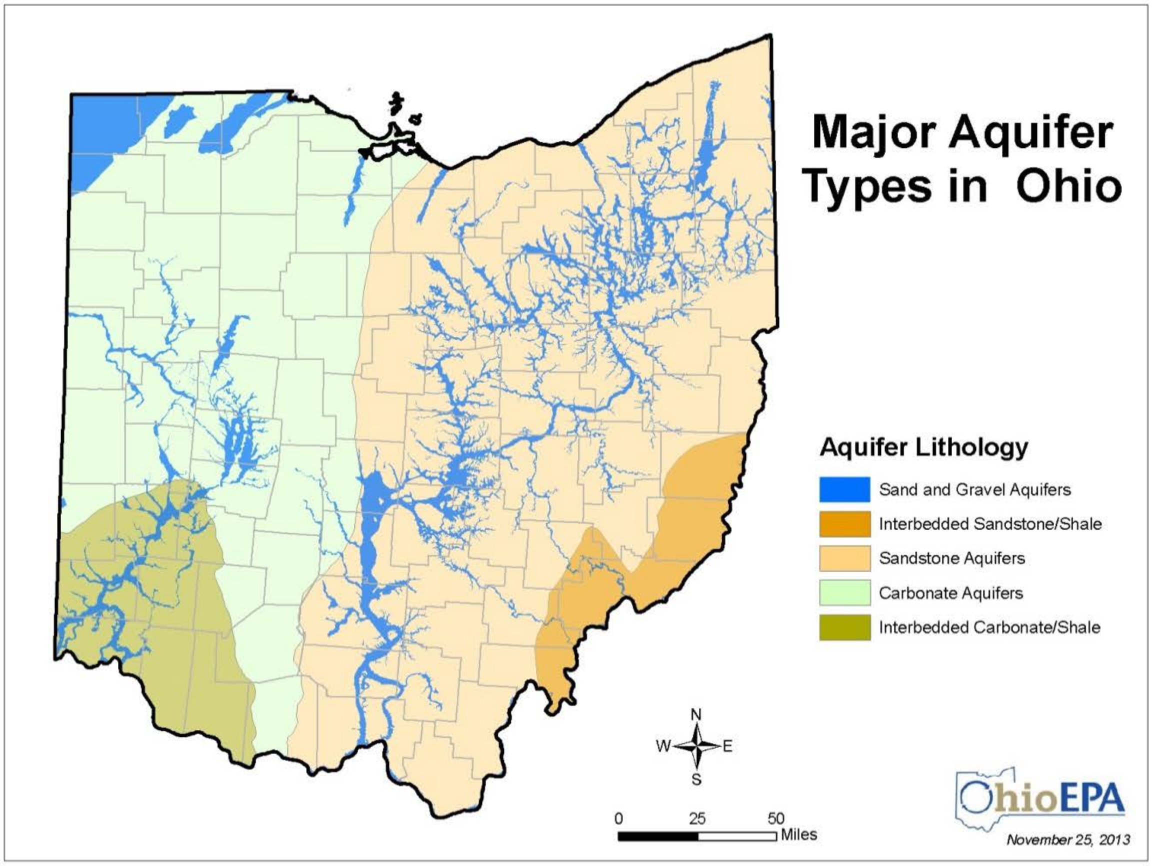


Figure M-1. Aquifer Types in Ohio modified from ODNR Glacial and Bedrock Aquifer Maps (ODNR, 2000; *http://www.dnr.state.oh.us/water/samp/default/tabid/4218/Default.aspx).*

Sandstone Aquifers - In eastern Ohio, Mississippian and Pennsylvanian sandstone units are the dominant bedrock aquifers (Figure M-1). Upper Paleozoic siltstone, sandstone, and conglomerate formations (Mississippian to Permian age) in eastern Ohio occur as numerous layers of siltstone and sandstone of variable thickness and areal extent separated by layers of shale and minor amounts of limestone, clay and coal. The sandstone units generally dip a few degrees to the southeast, toward the Appalachian Basin. Some of the thicker sandstones and conglomerates can yield 50 to 100 gpm, but 25 gpm is good for these aquifers. The more productive stratigraphic units include:

- **Pennsylvanian Sharon through Massillon Formations, and the Homewood Sandstone within the Pottsville and Allegheny Groups** - These sandstones were deposited on a stable coastal plain under conditions of rising sea level. These aquifers are most commonly used in the northern areas of Eastern Ohio. To the southeast, farther into the Appalachian Basin, the water in these units is generally too saline for drinking.

- **Mississippian Berea Sandstone, Cuyahoga Group, Logan and Blackhand Formations** - These siltstones and sandstones with minor conglomerate were sorted and deposited in deltaic complexes from material eroded from the Acadian Mountains (Late Devonian uplift) to the east. These units also extend to the SE, farther into the Appalachian Basin, but as with the Pennsylvanian units, the water becomes too saline for drinking.

In southeastern Ohio, Upper Pennsylvanian and Permian stratigraphic sections include low-yielding aquifers. The bedrock consists of varied sequences of thin-bedded shales, limestones, sandstones, clays, and coals of the Pennsylvania, Conemaugh and Monongahela Groups and the Permian Dunkard Group. Yields below five gpm are common in these areas:
http://www.dnr.state.oh.us/water/samp/bdrkyldsml/tabid/4215/Default.aspx

Carbonate Aquifers - Carbonate bedrock is the dominant aquifer in western Ohio (Figure M-1). Silurian and Middle Devonian limestone and dolomite reach a total thickness of 300 to 600 feet, and are capable of yielding from 100 to over 500 gpm. Higher production units are associated with fractures and dissolution features that increase the permeability. The high production aquifers, in order of deposition, are fractured or karst Silurian sub-Lockport/ Lockport Dolomite and equivalent units, the Salina Group, consisting of the Tymochtee and Greenfield Dolomites, and the Undifferentiated Salina Dolomite and equivalent evaporites. The Devonian Columbus and Delaware Limestones, exposed along the eastern edge of the Silurian Dolomites, and equivalent Devonian units in the northwest corner of Ohio (Detroit River Group, Dundee Limestone, ,Silica Formation, , and Ten Mile Creek Dolomite) are productive carbonate aquifers. These carbonates were generally deposited in warm, shallow seas with limited input of sediment from continental sources. Where the Devonian limestone is overlain by 100 feet or more of Devonian shale, the water quality is poor and generally cannot be considered a drinking water source.

The southwestern portion of the state is underlain by inter-bedded lower Ordovician carbonates and shales. These undivided Ordovician units are dominated by shale (Figure M-1). As a result, well yields are generally less than 10 gpm, and in many areas are less than one gpm. In this area, public water systems depend on the buried valley aquifers as the main ground water source. The low yielding aquifers are only practical for low volume use, and consequently, this aquifer is not discussed further in this report. Another area with low yields is the region of Devonian shale that overlies the Columbus and Delaware Limestone aquifers. The narrow north-south trending area of the Devonian shale in central Ohio curves eastward along the Lake Erie shoreline. These shale bedrock units are poor aquifers yielding less than 5 gpm. In addition, hydrogen sulfide is frequently present in these shales, which causes water quality problems.

In an effort to characterize ground water quality for the professional/technical community and the general public, DDAGW has started writing technical reports and fact sheets on the distribution of specific parameters in Ohio. The goal of the technical reports is to provide water quality information from the major aquifers, exhibit areas with elevated concentrations, and identify geologic and geochemical controls. This information is useful for assessing local ground water quality, water resource planning, and evaluating areas where specific water treatment may be necessary. A series of parallel fact sheets, targeted for the general public, provide basic information on the distribution of the selected parameters in ground water. The information in the fact sheets is presented in a less technical format, addresses health effects, outlines treatment options, and provides links to additional information.

The first technical report and fact sheet was Fluoride in Ohio's Ground Water (February 2012). Fluoride exhibits elevated concentrations in association with carbonate aquifers in western and northwestern Ohio. Fluorite was deposited as a secondary mineral in association with non-economic deposits of sphalerite and galena along fractures in the Silurian and Devonian carbonate aquifers. These minerals were deposited from Late-Paleozoic brines expelled from the Appalachian Basin. Dissolution of fluorite as water flows through the fractured carbonate aquifers produces the elevated fluoride. Figure M-2 illustrates the distribution of fluoride concentrations in Ohio's ground water. The MCL value for fluoride (4.0 mg/L) is seldom exceeded, but the SMCL value (2.0 mg/L) is exceeded in northwestern Ohio.

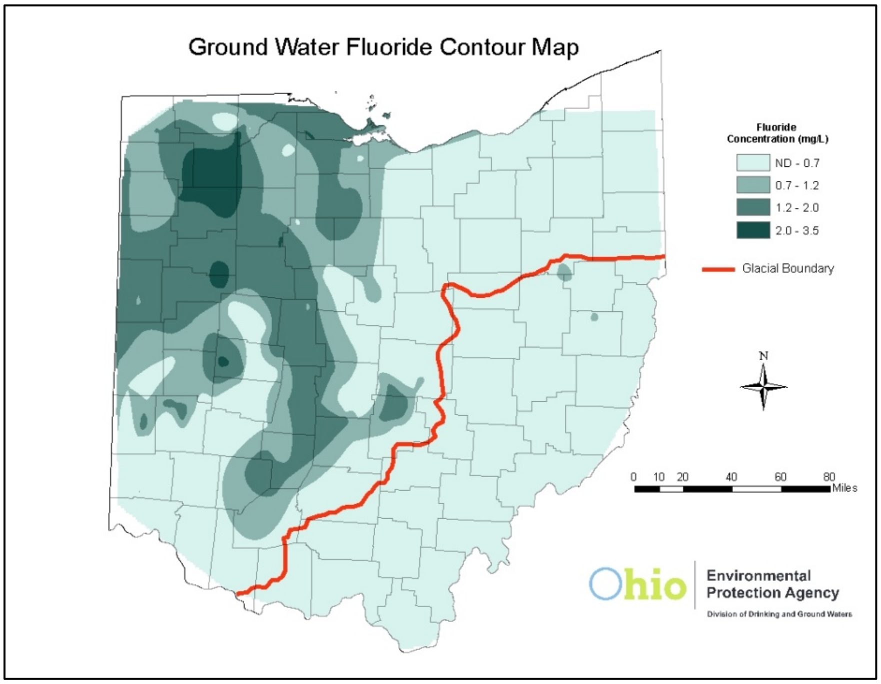


Figure M-2. Fluoride contour map of Ohio Ground Water

The second technical report and fact sheet was Radionuclides in Ohio's Ground Water (October 2013). In Ohio, gross alpha and radium radiation are generally low, with very few public water systems exceeding the gross alpha MCL of 15 pCi/L or the combined radium-226/radium-228 MCL of 5 pCi/L. The widespread low levels suggest the predominant sources of gross alpha and radium are low concentrations of naturally occurring uranium and thorium and their daughter products (including radium and radon) within Ohio's geologic strata. The distribution of radionuclide detections is consistent with the occurrence of uranium and thorium, based on their geochemistry and geologic processes. These low levels of radionuclide radiation are consistent with Ohio's surficial and shallow bedrock geology and the geologic environments of Ohio's major aquifers. Figure M-3 illustrates the distribution of gross alpha in Ohio's ground water. Generally, gross alpha values are low with a few scattered elevated values in northwest Ohio. These are attributed to concentration of uranium in carbonates with high organic content with subsequent weathering concentration of uranium and radium in calcareous soils.

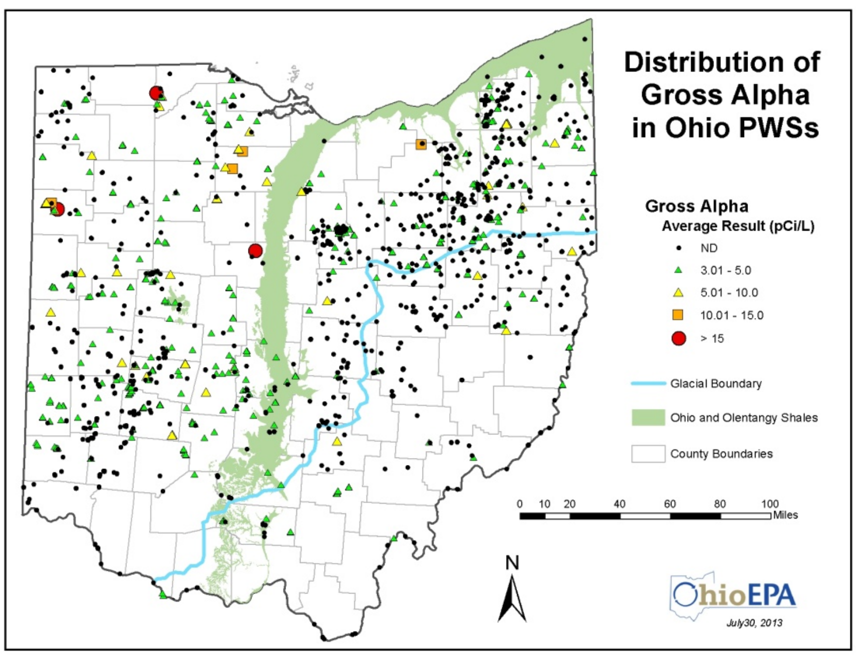


Figure M-3. Average Gross Alpha in Ohio Ground Water

M4. Site-Specific Ground Water Contamination Summary

Table M-2 (based on Table 5-3, U.S. EPA 305(b) Guidelines, 1997) provides a summary of the sites that have verified ground water contamination in Ohio. These data come from various state programs and the quality of these data varies. Because the specific hydrogeologic settings for many of these sites is not included in the databases or is unknown, only a statewide summary is provided. Additional information is provided below for each program or subset of sites listed in Table M-2.

Table M-2. Ground water contamination summary.
Hydrogeologic Setting: Statewide
Data Reporting Period: As of September, 2013

Source Type	Number of sites	Number of sites that are listed and/or have confirmed releases	Number of sites with confirmed ground water contamination	Contaminants
NPL - U.S. EPA	37	37	34	Mostly VOCs and heavy metals; also, SVOCs, PCBs, PAHs and others
CERCLIS (non-NPL) - U.S. EPA	438	438	20	Varied
DOD/DOE	128[a]	71	68	Varied
LUST	33,858[b]	3,355	233[c]	BTEX
RCRA Corrective Action	130	130	130	VOCs, heavy metals, PCBs, and others
Underground Injection	Class[d]: I - 10 II - 362 III - 46 IV - 0 V - 50,000+	 0 0 0 0 NA	 0 0 0 0 NA	
State Sites[e]	636	636	253[f]	Varied
Nonpoint Sources	NA	NA	NA	

Notes: NA - Numbers not available

[a] Includes DOE, DOD, FUSRAP and FUD sites

[b] Includes only active LUST sites - Source: Ohio's State Fire Marshal, Bureau of Underground Storage Tank Regulations

[c] Sites in Tier 2 or Tier 3 cleanup stages. Source: Ohio's State Fire Marshal, Bureau of Underground Storage Tank Regulations

[d] Class II and Class III injection wells regulated by the Ohio Department of Natural Resources, Division of Oil and Gas Resources. Class IV injection wells are illegal in Ohio. The total number of Class V injection wells in Ohio is unknown.

[e] Facilities in Ohio EPA's Ground Water Impacts database

[f] A site is considered to be contaminating ground water if the "Uppermost Aquifer" or "Lower Aquifer" is noted to be impacted, found in Ohio EPA's Ground Water Impacts database

Federal National Priorities List (NPL): Currently, 37 sites in Ohio are on the NPL, most of which (34) have been found to be affecting ground water quality. The primary contaminants are volatile organic chemicals (VOCs) and heavy metals.

CERCLIS (non-NPL): Ohio has 438 sites in the federal CERCLIS database. Of these, 20 are known to have had a release to ground water.

DOD/DOE: The 128 sites on this list are the Department of Defense (DOD)/Department of Energy (DOE) sites in Ohio, including those that are Formerly Used Defense Sites (FUDS) and Formerly Utilized Sites Remedial Action Program (FUSRAP) sites. Of these, 68 have had confirmed releases to ground water.

Leaking Underground Storage Tanks (LUST): In Ohio, underground storage tanks (USTs) are under the jurisdiction of the State Fire Marshal, Bureau of Underground Storage Tank Regulation (BUSTR). Current data indicates that more almost 33,000 sites have been found to be leaking. Of these, 3,355 have confirmed releases, with 233 having a release to ground water. The primary contaminants are the petroleum products of benzene, toluene, ethylbenzene, and xylenes (BTEX).

RCRA Corrective Action: Currently, 130 facilities are in RCRA corrective action. All of these have confirmed releases to ground water. The primary contaminants are VOCs and heavy metals. This information was obtained from the RCRA Facility Database, an internal DDAGW tracking system.

Underground Injection: There are five classes of underground injection wells:

1) Class I wells inject hazardous wastes or other wastewaters beneath the lowermost aquifer;
2) Class II wells inject brines and other fluids associated with oil and gas production beneath the lowermost aquifer;
3) Class III wells inject fluids associated with solution mining of minerals beneath the lowermost aquifer;
4) Class IV wells inject hazardous or radioactive wastes into or above aquifers (these wells are banned unless authorized under a federal or state ground water remediation project; there are none in Ohio);
5) Class V wells comprise all of the injection wells not included in Classes I-IV.

The Ohio Department of Natural Resources, Division of Oil and Gas Resources regulates Class II (385) and Class III (47) wells. The number of Class II wells (brine injection wells) is increasing because of their use in disposal of fluids used in oil and gas drilling and shale gas development.

Ohio EPA DDAGW regulates Class I (10), Class IV (0), and Class V (+50,000) wells. Although owners and operators of Class V wells are required to register or permit their wells, there are still many that are unknown and unregistered throughout the state.

State Sites: State sites include landfills, RCRA-regulated hazardous waste facilities, unregulated sites (pre- RCRA), and sites investigated through the Voluntary Action Program (VAP). Ground water contamination summary information concerning many of these sites is tracked in the Ground Water Impacts Database, maintained by Ohio EPA - DDAGW. The database consists of sites with verified contaminant release to ground water. As of September, 2013, the database contained 636 sites. Of the 636, 253 have affected ground water quality within the uppermost aquifer or lower aquifer.

Figure M-4 illustrates the distribution of the sites with verified ground water quality releases as recorded in the Ground Water Impacts Database. Several types of saturated ground water zones or aquifers are identified for each site depending on the regulatory program and the zone being monitored. The monitored zones include but are not limited to significant zones of saturation and uppermost aquifers.

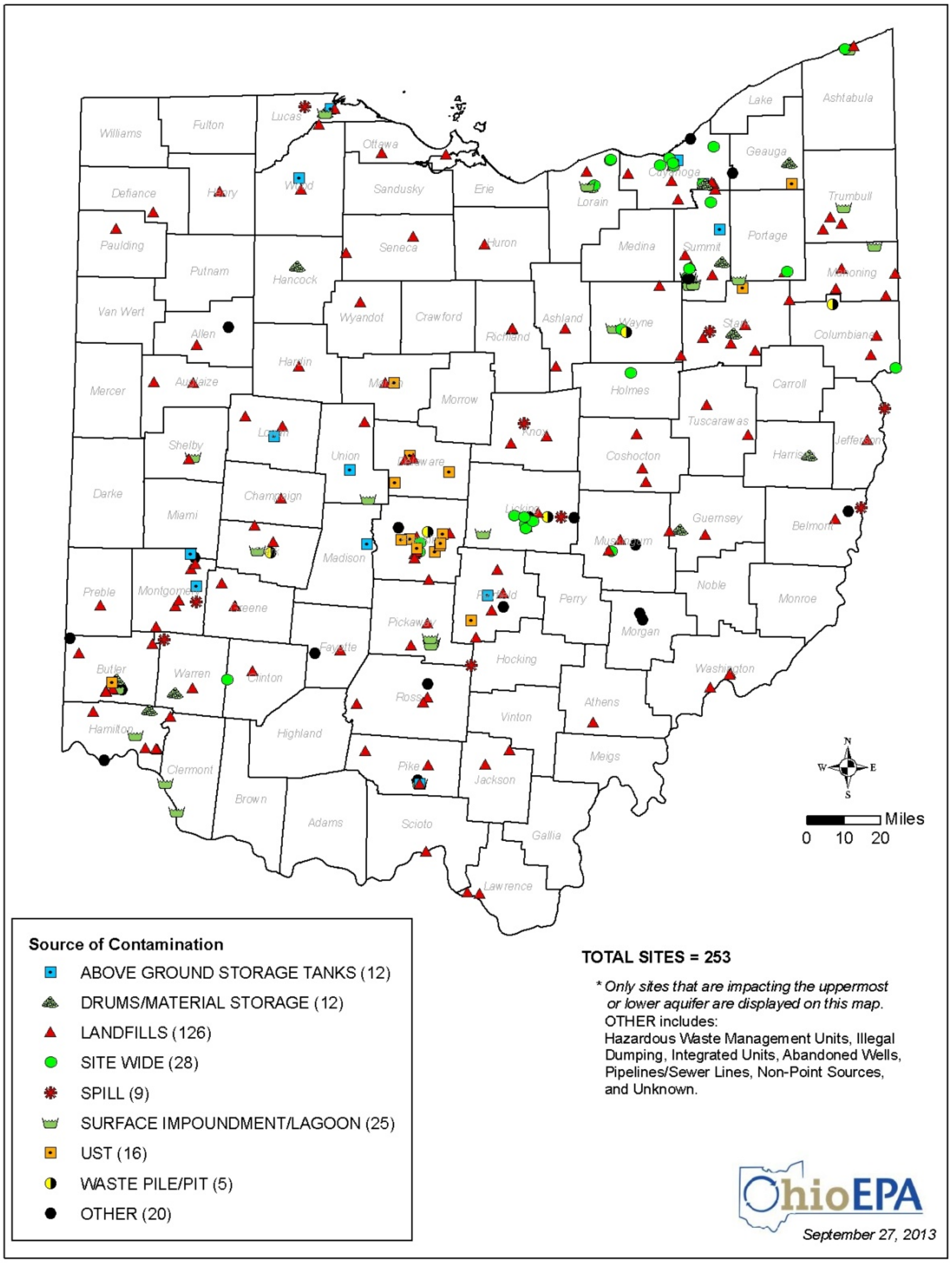


Figure M-4. Locations of sites with documented ground water impacts in Ohio.

For the purpose of Figure M-4 (and state sites in Table M-2), contamination had to be present in either the uppermost aquifer or lower aquifer to be counted as having ground water contamination (253 facilities). The type of contaminants varies, with the majority being VOCs and heavy metals. The majority of the sites are concentrated near large, urban areas, such as Cincinnati/Dayton in southwest Ohio, Columbus in central Ohio, and the Cleveland/Akron area in northeast Ohio. Of the 253 sites, landfills are found to contribute the most to ground water contamination (126, or 51%). Most likely, these are from older, unlined landfills, many of which are currently closed.

M5. Major Sources of Ground Water Contamination

Data show that much of Ohio's ground water is of high quality and has not been widely influenced by anthropogenic activities, but individual cases of contamination are documented every year from point (site-specific locations) and nonpoint sources. Ohio has a diverse economy, and the state uses and produces a range of potential contaminants, that are applied, stored, and disposed of in various land use practices. Consequently, ground water quality is susceptible to contamination from a range of contaminants and a variety of land use activities. Selecting major sources of contamination is subjective because the selection is scale-dependent. For an individual with contaminated water, the major source is the source that contaminates their well, regardless of the major sources identified for the state. From a statewide perspective, major sources are discussed below.

The ten major sources of ground water contamination in Ohio are indicated in Table M-3 (Table 5-1, U.S. EPA 305(b) Guidelines, 1997) by checks (✓). These data were obtained from two main sources: Ohio's Source Water Assessment and Protection (SWAP) Program and DDAGW's Ground Water Impacts Database. The SWAP Program has completed an inventory of the potential sources of ground water contamination in the delineated Drinking Water Source Protection Areas. Ninety-nine percent (99%) of the active public water systems that use ground water have had an inventory conducted, an analysis of the aquifer's susceptibility to contamination and a determination of whether the ground water quality has been impacted by anthropogenic activities. The Ground Water Impacts Database provides information regarding sites where contamination of ground water has been confirmed. These data were evaluated and those sources of highest concern were given a check mark (✓) in Table M-3.

Some of the "potentially high priority" sources, indicated by crosses (×), were selected based on professional knowledge of the types of sources that exist in Ohio. These sources, such as animal feedlots and mining, are limited in their extent, or are concentrated in regions of the state and may not be sited close to public water system well fields. Thus, they do not rank in the highest priority sources. However, where they are prevalent, these sources may be a threat to ground water resources, especially in areas with sensitive hydrogeologic settings. Land use activities within sensitive areas have a greater potential of affecting ground water quality

Table M-3. Major sources of potential ground water contamination.

Contaminant Source	Highest-Priority Sources	Factors Considered in Selecting a Contaminant Source	Contaminants
Agricultural Activities			
Agricultural chemical facilities			
Animal feedlots	×	5, 6, 8	E, J, K, L
Drainage wells			
Fertilizer applications (manure application)	✓	1, 2, 3, 4, 5	E, J, K, L
Irrigation practices			
Pesticide applications			
On-farm agricultural mixing and loading			
Land application of manure			
Storage and Treatment Activities			
Land application			
Material stockpiles			
Storage tanks (above/below ground)	✓	1, 2, 3, 4, 5, 6, 7	C, D, H, M
Surface impoundments	×	6	G, H, M
Waste piles			
Waste tailings			
Disposal Activities			
Deep injection wells			
Landfills	✓	1, 2, 3, 4, 5, 6	A, B, C, D, H, M
Septic systems	✓	1, 2, 3, 4, 5, 6	E, H, J, K, L
Shallow injection wells	✓	1, 2, 3, 4, 5, 6, 8	C, D, G, H, M
Other			
Hazardous waste generators			
Hazardous waste sites	✓	1, 2, 3, 4, 5, 6, 7	A, B, C, D, H, I, M
Large industrial facilities			
Material transfer operations			
Mining and mine drainage	×	6, 8	G, H
Pipelines and sewer lines	✓		D, E, J, K, L
Salt storage and road salting	✓	6	G
Spills	×	6	C, D, H, M
Transportation of materials			
Urban runoff (storm water management, storm drains)	✓	2, 4	A, B, C, D, G, H
Small-scale manufacturing and repair shops	✓	4, 6	C, D, H, M

Notes: (✓) Highest Priority;
(×) Potentially High Priority

Factor and Contaminant codes on next page.

FACTORS
1. Human health and/or environmental risk (toxicity)
2. Size of the population at risk
3. Location of the sources relative to drinking water sources
4. Number and/or size of contaminant sources
5. Hydrogeologic sensitivity
6. State findings, other findings
7. Documented from mandatory reporting
8. Geographic distribution/occurrence

CONTAMINANTS
A. Inorganic pesticides
B. Organic pesticides
C. Halogenated solvents
D. Petroleum compounds
E. Nitrate
F. Fluoride
G. Salt/Salinity/brine
H. Metals
I. Radionuclides
J. Bacteria
K. Protozoa
L. Viruses
M. Other (VOCs)

Contaminant Source Discussion - All of the sources listed in Table M-3 are potential contaminant sources in Ohio and each may cause ground water quality impacts at a local scale. The sources identified as "highest priority" or "potentially high priority" are listed below in the order presented in Table M-3 and discussed briefly to provide additional information.

(✓) Highest Priority Sources

- **Fertilizer Applications**: Use and handling of fertilizers, manure, and biosolids can cause ground water pollution. Human and animal biosolids used as fertilizer and chemical fertilizers contribute to nitrate contamination in ground water. Nitrate concentrations in ground water represent one of the better examples of the widespread distribution of nonpoint source pollution. Non-agricultural sources, such as lawn fertilization, sludge application, and septic systems also contribute to localized nitrate ground water contamination. Public water systems utilizing sand and gravel aquifers have higher average nitrate levels than PWSs using sandstone and carbonate aquifers, primarily due to the higher vulnerability of unconsolidated aquifers and the shallower nature of the sand and gravel aquifers.

- **Storage Tanks (Underground and Above-ground):** There are 3,355 USTs known to be leaking or undergoing remediation in Ohio. Of these, 255 have been located in drinking water source protection areas for public water systems using ground water. Above-ground tanks are also prevalent throughout Ohio, with 1,065 located in a drinking water source protection area for public water systems using ground water. Many of these are smaller tanks used to store fuel oil for heating individual homes, and many are old and rusty with no containment in the event of a leak or spill. Leaking above-ground storage tanks from commercial and industrial facilities are less of an issue. There are only 12 documented in the Ground Water Impacts database known to be contaminating ground water from regulated hazardous waste facilities.

- **Landfills:** Currently, there are 126 landfills with documented ground water contamination in Ohio. This constitutes almost 50 percent of the sites known to be affecting ground water quality based on information in Ohio EPA's Ground Water Quality Impacts database. Most likely, these are from older, unlined landfills, many of which are currently closed. The current siting, design, and construction standards for landfills are more stringent than twenty years ago, with the result that new landfills have significantly lower potential to impact ground water quality. Current efforts to monitor construction and demolition debris (C&DD) landfills are characterizing ground water quality at C&DD sites.

- **Septic Systems:** Over 1,000,000 household wastewater systems, primarily septic tanks and leach fields, or in some cases injection wells, are present throughout the rural and unsewered suburban areas of Ohio. A number of these systems are improperly located, poorly constructed, or inadequately maintained, and may cause bacterial and chemical contamination of ground water which may supply water to nearby wells. Improperly operated and maintained septic systems are considered significant contributors to elevated nitrate levels in ground water in vulnerable geologic settings (e.g., shallow fractured bedrock and sand and gravel deposits). More than 1,500 septic systems are located in drinking water source protection areas.

- **Shallow Injection Wells:** Class V injection wells are widespread throughout the state. High concentrations of Class V injection wells are most likely found in areas with sensitive sand and gravel aquifers. It is estimated that Ohio has over 50,000 class V injection wells. The fact that these wells are used to inject fluids directly into vulnerable aquifers in the State is the main cause for concern. These shallow injection wells provide a direct pathway for nonpoint source contamination and illegal waste disposal into vulnerable aquifers. Ohio has closed **583** motor vehicle waste disposal wells (e.g., oil, radiator fluids, etc.) since 2000.

- **Hazardous Waste Sites:** Ohio generates a large amount of hazardous waste. Legacy hazardous waste sites are a serious threat to ground water. There are 63 RCRA hazardous waste facilities, 15 Voluntary Action Program sites, and 61 unregulated hazardous waste remediation sites with documented releases to ground water (uppermost or lower aquifer) based on the Ground Water Impacts Database.

- **Pipelines and Sewer Lines:** Pipelines and sewer lines all have potential for failure with release of the transported material. In addition, the construction of these lines, with the pipe embedded in permeable material, allows the trench to provide rapid flow paths for other surface contaminants. This is especially true if the trench is dug into fractured bedrock. Numerous gas, oil, and industrial pipelines (1,132) and sewer lines (694) have been inventoried in drinking water source water protection areas.

- **Salt Storage and Road Salting:** The widespread use of salt or mixtures of salt and sand for deicing roads has been documented as a nonpoint source contributor of sodium and chloride contamination of shallow ground water (Jones and Sroka 1997; Mullaney et al. 2009). Spreading of salt on roads certainly contributes to ground water quality impacts, but the greater impact is associated with salt storage. Over the past two years, Ohio EPA has documented impacts to ground water at numerous salt storage facilities, including salt storage piles in drinking water source protection areas. Eighty-one (81) salt storage piles were identified in or near drinking water source protection areas with 62 of these located in sensitive aquifer settings. Most of these sites had adequate covering and pads. Ten sites were selected for additional investigation, two of which exhibited elevated chloride concentrations in ground water due to leaching of brine from the salt pile. In addition to addressing these sites, Ohio is exploring ways to encourage implementation of BMPs for proper salt storage. Alternative chemicals like acetate-based deicers in combination with reduced salt usage are being promoted in pollution prevention programs. The workgroup, consisting of members from the Ohio Water Resources Council and the State Coordinating Committee on Ground Water, developed

Recommendations for Salt Storage: Guidance for Protecting Ohio's Water Resources, located on the web at: http://www.ohiodnr.com/Portals/23/pdf/OWRC%20Salt%20Storage%20Guidance.pdf.

- **Suburban Runoff (including storm drains and storm water management):** With expanding suburban areas, nonpoint source contamination from suburban/urban runoff is an increasing source of ground water contamination, in contrast with most of the other sources discussed. In addition, the practice of constructing storm water retention basins increases the likelihood that storm water runoff infiltrates into ground water. More than 1,000 storm drains have been located in drinking water source protection areas, with many of these going directly to nearby water bodies. Elevated chloride is documented in urban areas within glacial aquifers by Mullaney et al. (2009) and positive trends in chloride concentrations in Ambient Ground Water Quality Monitoring data are present at some sites.

- **Small-Scale Manufacturing and Repair Shops:** Small-scale manufacturing and repair shops number more than 1,300 in drinking water source protection areas. These include: auto and boat repair shops and dealers, gas stations, junk yards, equipment rental and repair, machine shops, metal finishing and welding shops, and other various small businesses. These businesses typically handle chlorinated solvents (for cleaning) and petroleum products. Limited knowledge of best management practices for handling and disposing of these products increases the risk of impacting ground water.

(✖) Potentially High Priority Sources

- **Concentrated Animal Feeding Operations (CAFO):** The growth of CAFOs in numbers and size makes them a significant potential source if the waste is not properly managed. The ground water threats associated with CAFOs are captured in other categories as well, such as manure, sludge, and fertilizer application and surface impoundments, so they are not considered one of the ten highest priority sources. Improper storage or management of the animal waste is the greatest threat to ground water contamination in sensitive hydrogeologic settings, but land application in solid or liquid form also poses risks for ground and surface water contamination.

- **Surface Impoundments:** Surface impoundments are one of the most common waste disposal concerns at RCRA facilities. Historically, they have been a major source for ground water contamination. Older impoundments were not subject to the same engineering standards as newer impoundments, and, consequently, the probability of fluids leaching to the ground water was greater. Current siting and engineering requirements have improved this situation. Twenty-five (25) surface impoundments are known to be contaminating ground water based on information obtained from Ohio EPA's Ground Water Impacts database, the vast majority being from regulated and unregulated hazardous waste facilities.

- **Mining and Mine Drainage:** The bedrock (Pennsylvanian Units) that underlies eastern Ohio includes significant coal resources. The disruption of the stratigraphic units and oxidation of sulfides associated with coal mining produces ground water contamination by acid mine waters. Acid mine waters are considered a significant threat to ground water in mined areas.

- **Spills and Leaks:** Leaks and spills of hazardous substances from underground tanks, surface impoundments, bulk storage facilities, transmission lines, and accidents are major ground water pollution threats. More than a thousand leaks and spills are reported each year. This release of chemicals into the surface and near surface environment is certainly one of the greatest threats to ground water quality.

The major sources of ground water contamination listed include point and nonpoint sources in roughly equal proportions. In strict terms, a point source is a discharge from a discernable, confined and discrete conveyance, but in practical terms, the distribution or spatial scale of a contaminant controls the designation of a source as point or nonpoint. For example, salt applied for de-icing along roads exhibits nonpoint source behavior, while salt stockpiles behave more like point sources, with the potential for continual release of concentrated brine that may affect ground water quality. This dichotomy is typical of many agricultural contaminants, manure spreading versus storage, fertilizer application versus storage or mixing sites. In Ohio, we generally have better documentation of ground water contamination associated with point source contamination than nonpoint source contamination due to the extensive ground water monitoring programs at regulated facilities.

Rapid runoff in glacial till areas overlying much of Ohio and drainage tiling have protected many of Ohio's aquifers from traditional nonpoint source pollution sources such as nitrate, chloride, pesticides or bacteria. However, in sensitive settings (e.g., sand and gravel aquifers, shallow bedrock aquifers), indicators of nonpoint source pollution are more clearly identified in Ohio's Ambient Ground Water Quality Monitoring Program and the public water system compliance monitoring data. However, these monitoring programs do not focus on shallow aquifers, which have a higher likelihood of being influenced by nonpoint source pollution such as agricultural practices.

M6. Summary of Ground Water Quality by Aquifer

Tables M-4A and M-4B (Table 5-4, U.S. EPA 305(b) Guidelines, 1997) summarize water quality compliance data from Ohio public water systems (PWSs) and raw water data from the Ambient Ground Water Quality Monitoring Program (AGWQMP), respectively. The compliance data for Ohio EPA's PWSs (Table M-4A) documents water quality for treated water (post processing) and some raw (untreated) water quality (like new well samples). Parameters that are generally unaffected by standard treatment, such as nitrate, may be used to characterize Ohio's ground water quality. DDAGW created the AGWQMP program (Table M-4B) to monitor "raw" (untreated) ground water. This program's goal is the collection, maintenance, and analysis of raw ground water quality data to measure long-term changes in the water quality of the Ohio's major aquifer systems.

Ohio does not have statewide ground water quality standards, so data for the major aquifers are summarized using percentages of primary maximum contaminant level (MCL) or secondary maximum contaminant level (SCML) parameters. Primary MCLs are the highest level of a contaminant that is allowed in public drinking water and are set as close to MCL Goals (a health-based standard) as feasible using the best available treatment technology and economic considerations. Primary MCLs are enforceable standards. Secondary MCLs are non-enforceable guidelines regulating contaminants that may cause cosmetic effects (such as skin or tooth discoloration) or aesthetic effects (such as taste, odor, or color) in drinking water.

Primary and secondary MCLs are used as practical benchmarks for water quality characterization in Tables M-4A and M-4B. Fifty percent of the MCL to the MCL is used as the range for the **"watch list"** determination. The PWSs or wells identified in this category may warrant additional monitoring to identify increasing trends. MCL exceedances are used as the criteria for the **"impaired"** category. Tables M-4A and M-4B were generated using the last 10 years of data (2003-2012) and mean concentrations of a parameter are used for deciding if a PWS or well is included in the watch list (50% to 100 % MCL) or impaired category (> MCL). Maximum concentrations of nitrate and nitrite are reported in these tables instead of averages, due to the acute nature of their health concerns.

Public Water System Compliance Data

Mean values were calculated from PWS compliance data for 2003-2012 to determine the number of PWSs on the watch list and in the impaired category. A ten year period of record was used to increase the statistical significance of the determination due to the infrequent sampling requirements (e.g., once per three year period). **PWSs included in the impaired category may not match Safe Drinking Water Act regulatory determinations of a violation due to the method of calculation.** An MCL exceedance for compliance is generally an annual average, so the decadal average presented in Table M-4A is not a compliance number, but rather a comparison to MCL values, as a benchmark to identify PWSs in the watch list and impaired categories.

Table M-4A lists all parameters with MCLs (and SMCLs) and summarizes the number of PWSs in the watch list and impaired category for both raw and treated water quality data. The results for each parameter are divided into the major aquifer types. The total number of PWSs with data used in these determinations is presented to allow comparison of the total number of PWSs to those that exhibit elevated concentrations of MCL parameters. Data from active and inactive systems is included in Table M-4A. For parameters with SMCLs, treated water data is limited or absent because compliance data is generally not required for aesthetic water quality issues.

Table M-4A. Counts of PWSs where 2003-2013 decadal mean values of compliance data occur in the Watch List and Impaired Category.
Note: presented by major aquifer types.

Chemical Group	Chemical	Standard Type	Standard	Major Aquifer	PWS Systems					
					Raw Water			Treated Water		
					Total # PWSs	Watch List > 50% to 100% MCL	Impaired > MCL	Total # PWSs	Watch List > 50% to 100% MCL	Impaired > MCL
Inorganics	Antimony	MCL	6 µg/L	Sand & Gravel	255	3		697	11	
				Sandstone	271	4	1	702	13	
				Carbonate	230	3		442	14	
	Arsenic	MCL	10 µg/L	Sand & Gravel	329	106	71	701	72	34
				Sandstone	293	73	18	709	36	12
				Carbonate	285	101	52	442	57	17
	Asbestos	MCL	$7x10^6$ fibers/L	Sand & Gravel	35			167		
				Sandstone	10			47		
				Carbonate	11			61		
	Barium	MCL	2 mg/L	Sand & Gravel	265	3		698	5	
				Sandstone	279	6	2	704	1	
				Carbonate	229	1	1	441	1	
	Beryllium	MCL	4 µg/L	Sand & Gravel	255	2		441		
				Sandstone	272			703		1
				Carbonate	228			441		
	Cadmium	MCL	5 µg/L	Sand & Gravel	260		1	697		
				Sandstone	272	1	1	703		
				Carbonate	228			441		
	Chloride	SMCL	250 mg/L	Sand & Gravel	235	7	2			
				Sandstone	271	18	13			
				Carbonate	219	3	3			
	Chromium	MCL	0.1 mg/L	Sand & Gravel	258			697		
				Sandstone	270	1	1	703	1	
				Carbonate	230			441		
	Cyanide	MCL	0.2 mg/L	Sand & Gravel	247			697		
				Sandstone	270			703		
				Carbonate	225			441		

Chemical Group	Chemical	Standard Type	Standard	Major Aquifer	PWS Systems					
					Raw Water			Treated Water		
					Total # PWSs	Watch List > 50% to 100% MCL	Impaired > MCL	Total # PWSs	Watch List > 50% to 100% MCL	Impaired > MCL
Inorganics	Fluoride	MCL	4 mg/L	Sand & Gravel	271	3		697	4	
				Sandstone	276	1		703		
				Carbonate	238	21		441	22	
	Iron	SMCL	0.3 mg/L	Sand & Gravel	263	15	191			
				Sandstone	271	44	167	1	1	
				Carbonate	252	29	174			
	Manganese	SMCL	0.05 mg/L	Sand & Gravel	237	53	127			
				Sandstone	271	49	167	1		
				Carbonate	222	66	59			
	Mercury	MCL	2 µg/L	Sand & Gravel	253			697		
				Sandstone	272			703	1	
				Carbonate	228			441		
	Nitrate * (Max Value)	MCL	10 mg/L	Sand & Gravel	317	17	9	1603	68	19
				Sandstone	303	6	4	2038	42	6
				Carbonate	259	7	8	1397	38	8
	Nitrite * (Max Value)	MCL	1 mg/L	Sand & Gravel	295			1608		
				Sandstone	292			2040		
				Carbonate	242			1406		
	Selenium	MCL	50 µg/L	Sand & Gravel	256			697		
				Sandstone	273			703		
				Carbonate	229	2		441		
	Silver	SMCL	0.1 mg/L	Sand & Gravel	225		1	8		
				Sandstone	260			1		
				Carbonate	213		1			
	Solids, Total Dissolved	SMCL	500 mg/L	Sand & Gravel	111	62	38			
				Sandstone	150	87	41			
				Carbonate	131	31	98			

Chemical Group	Chemical	Standard Type	Standard	Major Aquifer	PWS Systems					
					Raw Water			Treated Water		
					Total # PWSs	Watch List > 50% to 100% MCL	Impaired > MCL	Total # PWSs	Watch List > 50% to 100% MCL	Impaired > MCL
Inorganics	Sulfate	SMCL	500 mg/L	Sand & Gravel	258	19	21			
				Sandstone	278	18	19			
				Carbonate	239	35	95			
	Thallium	MCL	2 µg/L	Sand & Gravel	254	2	1	697	8	
				Sandstone	271		1	703	7	
				Carbonate	228	1		441	2	
	Zinc	SMCL	5.0 mg/L	Sand & Gravel	131					
				Sandstone	128					
				Carbonate	108	1				
Volatile Organic Chemicals	1,2-Dichloroethane	MCL	5 µg/L	Sand & Gravel	296			702		
				Sandstone	304			711		
				Carbonate	248			446		
	1,1-Dichloroethylene	MCL	7 µg/L	Sand & Gravel	297	1		703		
				Sandstone	304		1	711		
				Carbonate	248			446		
	1,2-Dichloropropane	MCL	5 µg/L	Sand & Gravel	298			703		1
				Sandstone	305			711		
				Carbonate	248			448		
	1,1,1-Trichloroethane	MCL	200 µg/L	Sand & Gravel	298			703		1
				Sandstone	305			711		
				Carbonate	248			446		
	1,1,2-Trichloroethane	MCL	5 µg/L	Sand & Gravel	298			703		
				Sandstone	305			711		
				Carbonate	248			446		
	1,2,4-Trichlorobenzene	MCL	70 µg/L	Sand & Gravel	298			703		
				Sandstone	304			711		
				Carbonate	248			446		

Chemical Group	Chemical	Standard Type	Standard	Major Aquifer	PWS Systems					
					Raw Water			Treated Water		
					Total # PWSs	Watch List > 50% to 100% MCL	Impaired > MCL	Total # PWSs	Watch List > 50% to 100% MCL	Impaired > MCL
Volatile Organic Chemicals	Benzene	MCL	5 µg/L	Sand & Gravel	297	1		703		
				Sandstone	305			711		
				Carbonate	246			446		
	Carbon Tetrachloride	MCL	5 µg/L	Sand & Gravel	298			703		
				Sandstone	305	1	1	711		
				Carbonate	248		1	446		
	Cis-1,2-Dichloroethylene	MCL	70 µg/L	Sand & Gravel	298			703		
				Sandstone	304			711		
				Carbonate	248			703		1
	Dichloromethane	MCL	5 µg/L	Sand & Gravel	297	2		703		1
				Sandstone	299	1	1	711	1	1
				Carbonate	247	1	1	446	1	1
	Ethylbenzene	MCL	700 µg/L	Sand & Gravel	298			703		
				Sandstone	305			711		
				Carbonate	248			446		
	Monochlorobenzene	MCL	100 µg/L	Sand & Gravel	298			703		1
				Sandstone	304			711		
				Carbonate	248			446		
	o-Dichlorobenzene	MCL	600 µg/L	Sand & Gravel	298			703		
				Sandstone	304			711		
				Carbonate	248			446		
	p-Dichlorobenzene	MCL	75 µg/L	Sand & Gravel	298			703		1
				Sandstone	303			711	1	
				Carbonate	248			446	1	
	Pentachlorophenol	MCL	1 µg/L	Sand & Gravel	5			93		
				Sandstone				39		
				Carbonate	1			39		

Chemical Group	Chemical	Standard Type	Standard	Major Aquifer	PWS Systems					
					Raw Water			Treated Water		
					Total # PWSs	Watch List > 50% to 100% MCL	Impaired > MCL	Total # PWSs	Watch List > 50% to 100% MCL	Impaired > MCL
Volatile Organic Chemicals	Styrene	MCL	100 µg/L	Sand & Gravel	298			703		1
				Sandstone	305			711		
				Carbonate	248	1		446		
	Tetra-chloroethylene	MCL	5 µg/L	Sand & Gravel	298	2	1	703		
				Sandstone	305		2	711	2	
				Carbonate	248			448	1	
	Toluene	MCL	1000 µg/L	Sand & Gravel	298			703		
				Sandstone	304			711		
				Carbonate	248			446		
	Trans-1,2-Dichloroethylene	MCL	100 µg/L	Sand & Gravel	298			703		1
				Sandstone	305			711		
				Carbonate	248			446		
	Trichloroethylene	MCL	5 µg/L	Sand & Gravel	298			703		
				Sandstone	305		1	711	1	
				Carbonate	247			703		
	Vinyl Chloride	MCL	2 µg/L	Sand & Gravel	297	3	2	702	1	1
				Sandstone	304			711		
				Carbonate	248			446		
	Xylenes, Total	MCL	10 mg/L	Sand & Gravel	297			703		
				Sandstone	301			711		
				Carbonate	247			446		
Pesticides and Synthetic Organic Chemicals	Alachor (Lasso)	MCL	2 µg/L	Sand & Gravel	248			703		
				Sandstone	268			713		
				Carbonate	220			448		
	Atrazine	MCL	3 µg/L	Sand & Gravel	247			703		
				Sandstone	269			713		
				Carbonate	220			448		

Chemical Group	Chemical	Standard Type	Standard	Major Aquifer	PWS Systems					
					Raw Water			Treated Water		
					Total # PWSs	Watch List > 50% to 100% MCL	Impaired > MCL	Total # PWSs	Watch List > 50% to 100% MCL	Impaired > MCL
Pesticides and Synthetic Organic Chemicals	Benzo(a)pyrene	MCL	0.2 µg/L	Sand & Gravel	3			92	1	
				Sandstone				44		
				Carbonate	2			19		
	Carbofuran	MCL	40 µg/L	Sand & Gravel	3			93		
				Sandstone				39		
				Carbonate	1			19		
	Di(2-ethylhexyl) adipate	MCL	400 µg/L	Sand & Gravel	4			92		
				Sandstone				44		
				Carbonate	4			19		
	Di(2-ethylhexyl) phthalate	MCL	6 µg/L	Sand & Gravel	4			95		
				Sandstone				44		
				Carbonate	4			21	1	
	Dinoseb	MCL	7 µg/L	Sand & Gravel	5					
				Sandstone						
				Carbonate	1					
	Diquat	MCL	20 µg/L	Sand & Gravel	3			99		
				Sandstone				43		
				Carbonate	1			18		
	Endothall	MCL	100 µg/L	Sand & Gravel	3			92		
				Sandstone				44		
				Carbonate	1			19		
	Ethylene Dibromide	MCL	0.05 µg/L	Sand & Gravel	5					
				Sandstone						
				Carbonate						
	Glyphosate	MCL	700 µg/L	Sand & Gravel	3			96		
				Sandstone				44		
				Carbonate	1			18		

Chemical Group	Chemical	Standard Type	Standard	Major Aquifer	PWS Systems					
					Raw Water			Treated Water		
					Total # PWSs	Watch List > 50% to 100% MCL	Impaired > MCL	Total # PWSs	Watch List > 50% to 100% MCL	Impaired > MCL
Pesticides and Synthetic Organic Chemicals	Methoxychlor	MCL	40 µg/L	Sand & Gravel	4			96		
				Sandstone	1			44		
				Carbonate	1			18		
	Simazine	MCL	4 µg/L	Sand & Gravel	247			703		
				Sandstone	269			713		
				Carbonate	220			448		
	Total Polychlorinated Biphenyls (PCBs)	MCL	0.5 µg/L	Sand & Gravel	3			96		
				Sandstone	1			44		
				Carbonate				18		
Organic Disinfection By-Products	Total Haloacetic Acids (HAA5)	MCL	60 µg/L	Sand & Gravel	76	3	1			
				Sandstone	51		1			
				Carbonate	53	2				
	Total Trihalomethanes (TTHM)	MCL	80 µg/L	Sand & Gravel	115	6	4			
				Sandstone	61	2				
				Carbonate	60	5	2			
Radiological	Gross Alpha (incl. + excl.)	MCL	15 pCi/L	Sand & Gravel	258	1		356		
				Sandstone	278	6		203	1	1
				Carbonate	229	13	3	151	4	
	Gross Beta	MCL	4 mrem/yr**	Sand & Gravel	141		1			
				Sandstone	162					
				Carbonate	126					
	Radium 226	MCL	5 pCi/L ***	Sand & Gravel	19			1		
				Sandstone	26	2	1	3		
				Carbonate	40	6	2	1		
	Radium 228	MCL	5 pCi/L ***	Sand & Gravel	131			326		
				Sandstone	141	3	2	185	1	
				Carbonate	126	2		157		

Blank spaces indicate no PWSs exceed the standards (zeros left out to highlight impacted PWSs).
nda Indicates no data available

* Numbers for nitrate and nitrite are based on maximum values to reflect the acute nature of the contaminant.
** If Gross Beta result is less than 50 pCi/L no conversion to mrem/yr is necessary - table used 50 pCi/L as standard.
*** MCL is for combined Radium 226 and Radium 228

With the exception of a new well analysis, there are no requirements for collecting and reporting raw water data, so the number of PWSs with raw water data is less than the number with treated water data. The PWS data were linked to geologic settings using the DDAGW Source Water Assessment data, which allowed the breakout of the data by major aquifer. In this analysis, any detection in raw water data was used to generate PWS averages. For treated water data, PWS averages were generated only if there were at least two detections of a parameter. The inorganic parameters that place numerous PWSs in the watch list and impaired category warrant additional analysis.

The number of PWSs in Table M-4A in the watch list and the impaired category are generally low; however, several parameters do exhibit higher numbers of PWSs in these groups. Fortunately, most of these occurrences are for secondary MCLs, not primary MCLs. That is, the water quality impacts documented are mostly aesthetic issues and are not health-based. Groups of parameters are discussed individually.

Inorganic Parameters
MCL Parameters
Only a few PWSs fall into the watch list or the impaired MCL category based on inorganic parameters. For treated water data, parameters with MCLs and <u>no</u> PWSs in the impaired category (values > MCL) include **antimony, asbestos, barium, cadmium, chromium, cyanide, fluoride, mercury, selenium, and thallium.** The use of detection limits at or greater than 50 % of the MCL and using the reporting limit for the non-detect value can result in PWS placed in the watch list with no detection of the parameter. The data has been reviewed to assure that PWS in the watch list have detected the parameter. Factors limiting the number of PWSs in these categories include limited solubility of the substance in water, low crustal abundance, local geology, and possibly treatment. For example, in treated water, fluoride has no PWSs that exceed the MCL, but 24 PWSs that draw water from carbonate aquifers exceed 50 percent of the MCL. This association is controlled by secondary fluorite mineralization along fractures and voids in limestone in northwest Ohio.

One parameter, beryllium, has a low numbers of PWSs in the MCL impaired category for treated water. For this parameter a single PWSs is found in the impaired category. This small number is consistent with the low solubility and scarcity of this metal in Ohio's geology. The use of decadal averages for building both watch list and impaired categories may overestimate the numbers of PWSs when compared to actual MCL or SMCL calculations (annual averages).

The number of PWSs with **arsenic** in raw water and treated water above the MCL (141 and 63, respectively) is consistent with the number of PWSs that DDAGW has worked with to reduce arsenic to meet the 2006 revised MCL of 10 µg/L. These systems are associated with reduced ground water and local areas of naturally occurring arsenic. Sand and gravel and carbonate aquifers are more likely than the sandstone aquifers to exhibit arsenic-impaired ground water. The number of PWSs currently exceeding the arsenic MCL is significantly less than what is listed in Table M4-A because numerous PWSs have installed treatment to remove arsenic since 2006. The elevated arsenic results collected from 2003 to 2006 are included in the ten years of data used to generate the PWS decadal averages that are calculated for Table M4-A and thus, result in impaired systems. Figure M-5 illustrates the distribution of the PWSs with arsenic in treated and/or raw water greater than the MCL as listed in Table M-4A. The local aquifer must be reduced for arsenic to be elevated in the ground water.

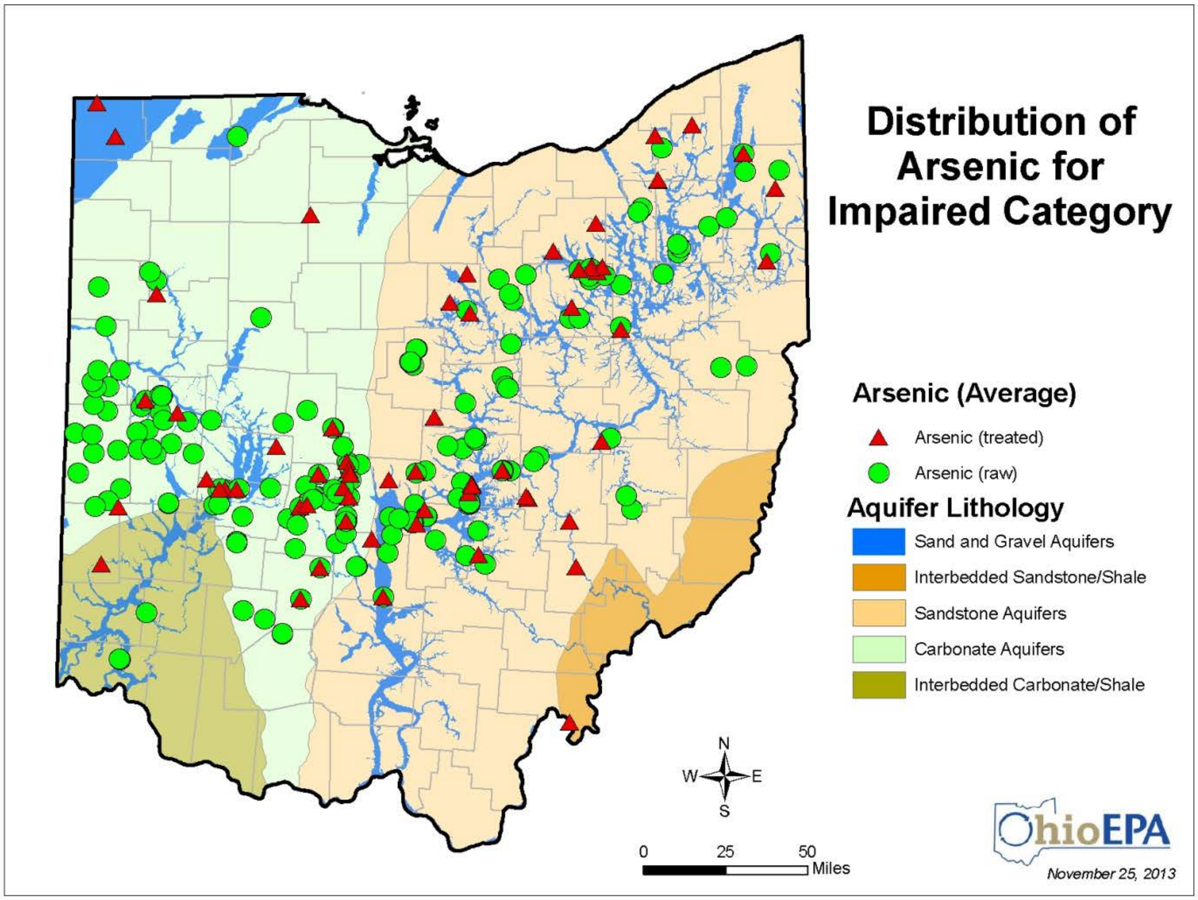


Figure M-5. Distribution of PWSs on impaired list for arsenic for both treated and raw waters.

SMCL Parameters

Secondary MCL parameters for drinking water are directed at non-health related issues such as taste and odor. PWSs do not collect compliance data for most parameters with SMCLs. Table M-4A utilized only compliance data and, consequently, it includes little data for treated water for parameters with SMCLs. The raw water data collected through new well samples, however, provides information on the distribution of these parameters.

Multiple PWSs display elevated **chloride**. The largest numbers of PWSs with elevated chloride are associated with the sandstone aquifers followed by sand and gravel aquifers. This may be to be related to limited natural oil and gas deposits occurring within aquifers, contamination of local aquifers from surface handling of oil and gas production brines, local salt storage facilities overlying sensitive aquifers, road salt application, or septic systems. Transportation routes are concentrated in the broad, flat buried valleys, and consequently, large salt piles are stored on these broad valleys, which are sensitive aquifers. Activities to address chloride contamination are discussed in the Major Sources of Ground Water Contamination section.

Iron and manganese, with similar oxidation-reduction solubility controls as arsenic, also exhibit elevated numbers of PWSs in the watch list and impaired category of Table M-4A for raw water. PWSs do not collect compliance data for iron and manganese since they have secondary MCLs. Table M-4A utilized only compliance data so little data for treated water is included for iron and manganese. The raw water numbers are controlled by the increased solubility of iron and manganese in reduced waters. The deeper wells generally exhibit more reduced conditions (e.g., reduced interaction with the atmosphere) and, consequently, higher iron and manganese. Iron is a common element and is present in all three major aquifers. For manganese, the carbonate aquifer is least likely to exhibit concentrations above the SMCL. Many PWSs remove iron and manganese, so the percentage of PWSs that exhibit impairments in treated water is significantly lower than in raw water.

Sulfate also has an SMCL and, consequently, less data exists for identifying water quality impacts and the data is for raw water. Nevertheless, a significant number of PWSs exhibit elevated sulfate. Figure M-6 illustrates the distribution of PWSs with sulfate on the watch list and impaired category.

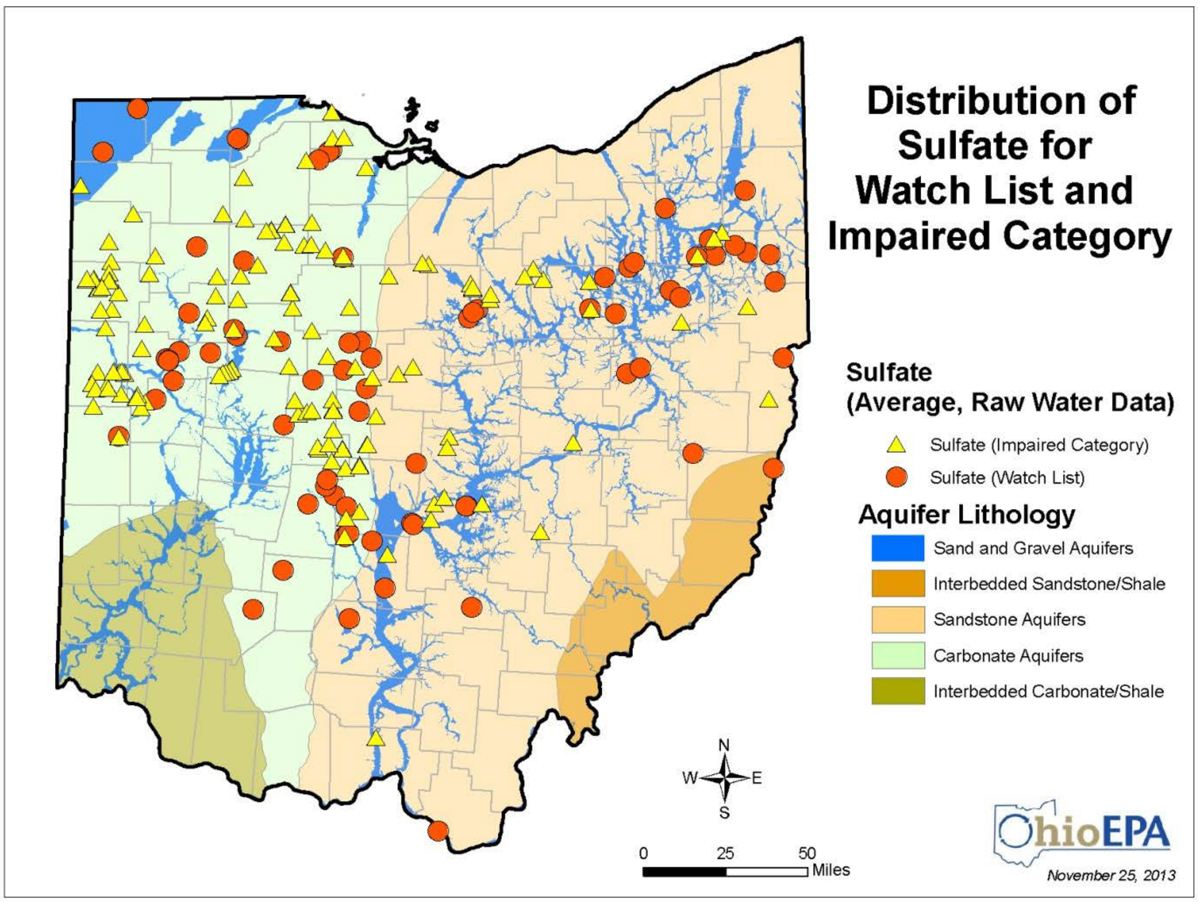


Figure M-6. Distribution of PWSs in impaired category and on the watch list for sulfate in raw water.

Although these sites are distributed in all major aquifers, the carbonate aquifers in NW Ohio exhibit the highest percentage of PWSs on the watch list and in the impaired category due to the presence of evaporates (Gypsum, $CaSO_4 \cdot 2H_2O$) in the Salina Formation in northwest Ohio.

Fluoride has no PWSs in the impaired category for raw or treated water, however, a number of PWSs exhibit watch list concentrations in treated and raw water. Fluoride is unusual in that it has a primary and secondary MCL, and the SMCL is 50 percent of the MCl. Thus, all of the systems on the watch list for the MCL, exceed the SMCL. The distribution of the fluoride watch list systems for both raw and treated water are plotted in Figure M-7. The distribution is similar to Figure M-2. The Fluoride Technical Report describes how fluorite, which was deposited as a secondary mineral in fractures in the carbonate aquifers, controls the distribution of elevated fluoride.

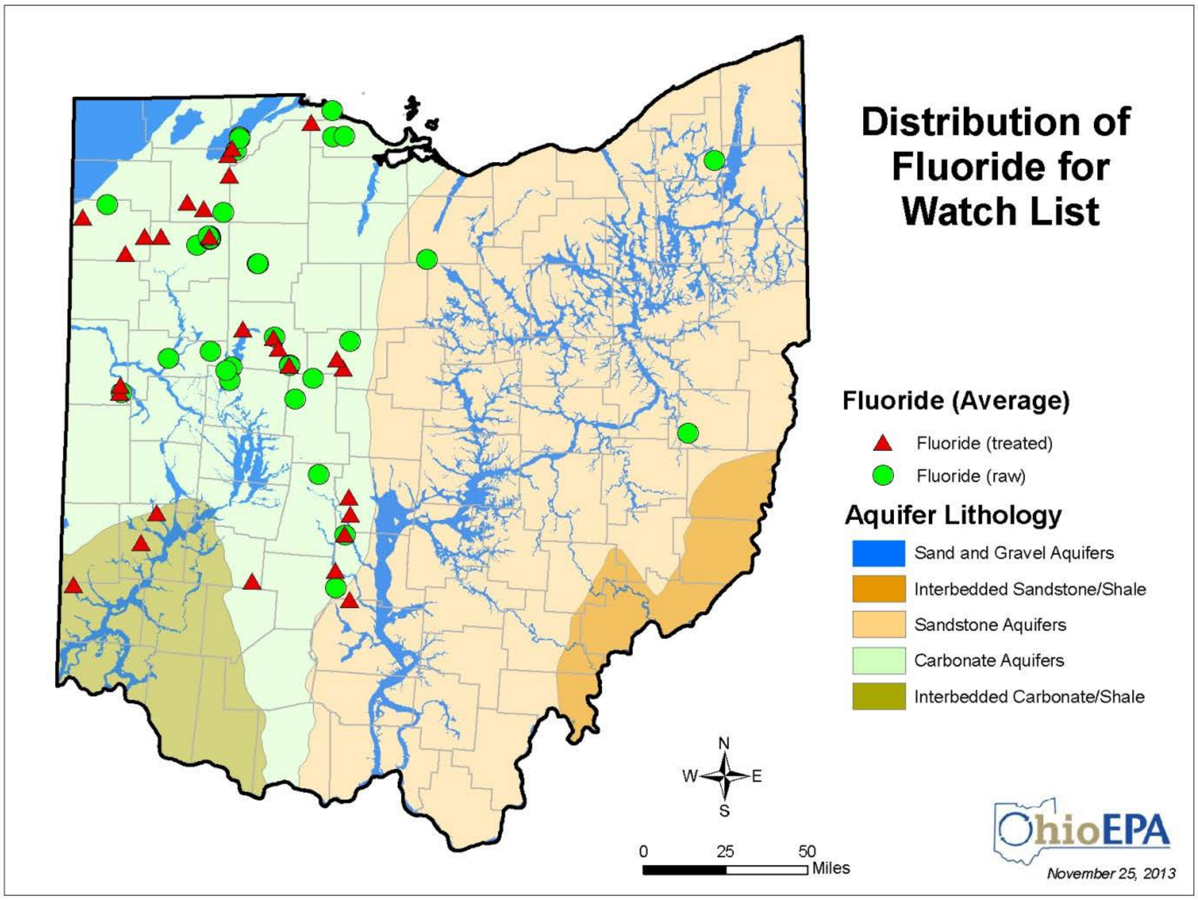


Figure M-7. Distribution of PWSs on fluoride watch list for treated and raw water.

For **nitrate and nitrite,** maximum values were used rather than average values to reflect the acute nature of the nitrogen MCLs. As a parameter that is stable in oxidized environments, nitrate is more likely to be present in shallower wells. Approximately 3.6 percent (181 of 5038) of PWSs in Table M-4A have maximum nitrate greater than 50% of the MCL. Approximately 46 percent of these PWSs are located in sand and gravel aquifer settings. A PWS that exceeds 50% of the nitrate MCL is required to sample for nitrate on a quarterly basis. Thus, over the last decade, at least 150 PWSs have been required to increase nitrate sampling to at least quarterly. For nitrate in treated water and raw water, 33 and 21 PWSs fall into the impaired category, respectively. PWSs with maximum results greater than the MCL do not necessarily indicate an MCL exceedance, which is an annual average.

PWSs with elevated nitrate tend to be associated with more sensitive aquifers such as buried valleys and areas of thin glacial drift over bedrock. Stable nitrate (where decadal averages are relatively high) tend to be found in systems that combine a shallow aquifer with rapid pathways between surface and ground water, and stable sub-oxic ground water. The number of PWSs with maximum nitrates with treated water in the watch list or impaired categories has decreased since 2010 based on the 2010 (243 PWSs), 2012 (227 PWSs) and 2014 (181 PWSs) Integrated Reports. This is encouraging, but probably reflects improved treatment or use of alternative sources, rather than reduction in nitrate loading. Figure M-8 illustrates the distribution of the PWSs with maximum nitrate above the MCL for both raw and treated water. The PWSs in Figure M-8 tend to cluster along buried valley aquifers.

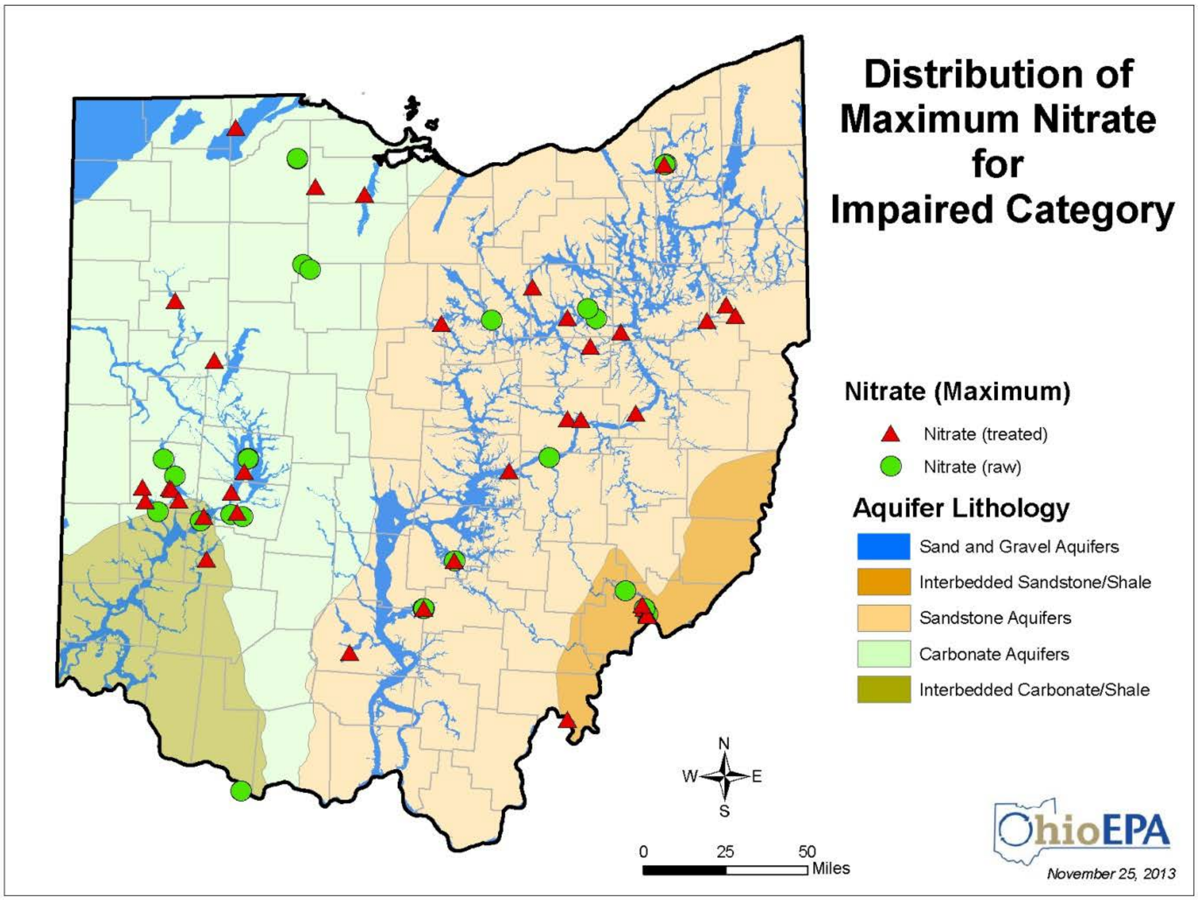


Figure M-8. Distribution of PWSs with maximum nitrate in treated and raw water greater than the MCL.

Organic Parameters

For the organic parameters, the mean concentration of treated water for nine organic parameters has placed PWSs in the impaired category: **1, 2-dichloropropane, 1, 1, 1-trichloroethane, cis-1, 2-dichloroethylene, dichloromethane, monochlorobenzene, p-dichlorobenzene, styrene, trans-1, 2-dichloroethylene,** and **vinyl chloride.** Two of these parameters are common solvents and the third is a compound used to make plastic. Dichloromethane (methylene chloride) is a known lab contaminant, but it is also possible that it can leach to ground water before it volatilizes, so it is included in Table M-4A. In addition to the PWSs identified above, there are about 15 PWSs not using a production well or treating for volatile organic chemicals due to ground water contamination that are not identified in this treated water analysis. The raw water data may include some of these systems, but if these ground water-based PWSs were not treating for organic removal they would be considered "impaired."

Pesticides and Synthetic Organics

The decadal compliance pesticide data identifies no pesticides on the impaired list. Table M-4A lists two pesticides and synthetic organics with PWSs included in the watch list: **benzo(a)pyrene** and **di(2-ethylhexyl)phthalate** as compared to none in 2012. This is largely due to the fact that analysis for 14 pesticides and synthetic organics was completed for this report versus analysis for three pesticides in the 2012 report. These data confirm that we see impact from pesticides and other organic compounds migrating to major aquifers, in spite of the protection that the till cover and tile drainage provide to protect Ohio ground water.

Radiological Parameters

For treated water, several PWSs are included on the watch list and the impaired category for **gross alpha** and one PWS is listed as in the watch list for **radium 228**. The limited number of PWSs in the watch list and impaired category is consistent with the Ohio's geologic setting having few natural sources of radionuclides. The exceptions are uranium associated with reduced geologic settings like glacial tills, the Ohio Shale, and coal deposits, as well as scattered thorium rich detrital grains in sandstones, but these settings are generally not utilized as aquifers. Gross beta compliance monitoring focuses on anthropogenic sources of radiation. The distribution of radionuclides is discussed in Radionuclides in Ohio's Ground Water (October 2013).

Ambient Ground Water Quality Monitoring Data

Mean values were calculated from the AGWQMP data (raw water) over the past ten years (2003-2012) to determine the number of wells in the watch list and impaired categories. These numbers are listed in Table M-4B by parameter and major aquifer. The number of wells with data used in the determinations is also presented to provide the relative number of wells that exhibit ground water quality with elevated concentrations of MCL parameters. A limited number of AGWMP wells are listed in the watch list and impaired category, as was the case for the PWS compliance data. The results for groups of parameters are discussed below.

Inorganic Parameters

The AGWQMP does not collect data for **antimony (except for one sandstone well), asbestos, beryllium, cyanide, mercury, nitrite, silver, and thallium**, so no comparison can be made to the PWS data. These parameters are not analyzed due to their historically low concentrations in Ohio ground water. No well waters have decadal averages that exceed the MCL or SMCL for **barium, chromium, fluoride, selenium, and zinc**. Several wells exceed 50 percent of the fluoride MCL. Most of these wells produce water from the carbonate aquifer, as was seen with PWSs in Table M-4A and Figure M-7. A few well means are greater than 50 percent of the **barium** MCL, but no impairments were identified. Averages for **cadmium and chloride** exceed the MCL or SMCL in a few cases. Eleven wells have chloride above 50 percent of the SMCL and three of these wells exceed the SMCL. The source of contamination is likely associated with improper storage of salt for road deicing, oil and gas drilling brine disposal or brines in bedrock aquifers.

For **nitrate**, sample maximums were used rather than averages to reflect the acute nature of the nitrate MCL. This approach makes it difficult to compare the nitrate numbers to numbers for other parameters in Table M-4B. Nitrate is stable in oxidized environments and, thus, is more likely to be detected in shallower wells that have rapid exchange pathways with the atmosphere. In the AGWQMP, the sand and gravel wells are generally the shallowest, and consequently, would be expected to exhibit the largest number of wells with maximum nitrate above the nitrate MCL. This is the case with about 8 percent of the sand and gravel wells exceeding 50 percent of the MCL. Three percent of the carbonate wells exceed 50 percent of the MCL, probably associated with sensitive, karst settings. No sandstone wells are on the watch list or in the impaired category for (maximum) nitrate. The AGWQMP tends to collect samples from higher production wells located deeper in aquifers; consequently, it is not the best program to evaluate ground water quality in shallow (e.g., 25 to 50 feet), sensitive aquifer settings.

Arsenic, iron, manganese, total dissolved solids (TDS), and sulfate mean concentrations result in significant numbers of wells on the watch list and in the impaired category. These are the same parameters identified in the PWS compliance data, with the addition of TDS. TDS is not required or collected for PWSs compliance data. Except for arsenic, all of these parameters have SMCLs, so treatment is not required. However, iron and manganese treatment is required for community public water systems. Many PWSs remove iron, with the additional benefit of manganese and arsenic removal. This occurs due to the similarity in their controls on solubility. Sulfate in the AGWQMP is elevated in carbonate aquifers due primarily to the presence of evaporates in the Salina Formation, in the upper portion of the Silurian carbonate aquifer. For the carbonate aquifers, over 60 percent of the ambient sites exceed 50 percent of the SMCL for sulfate, which is significantly higher than the percentage for the sandstone and sand and gravel aquifers (12 % and 9 % respectively). The elevated TDS in raw water results from the relative solubility of aquifer material and the residence time for ground water in all of Ohio's major aquifers. The carbonate aquifers generally have higher mean TDS, but all three main aquifers exhibit high percentages of ambient sites with TDS exceeding 50 percent of the SMCL.

Organic Parameters

Detection of organic parameters at and above watch list concentrations is not common. Detected organic parameters above the MCL include **trichloroethylene and vinyl chloride**. These organic solvents were detected in PWSs raw water samples as listed in Table M-4A.

Pesticides – No pesticides were detected in the AGWQMP wells above 50 percent of the MCL. The AGWQMP does not analyze for pesticides on a regular basis, as reflected in the low number of wells listed for pesticides, due to the lack of pesticide detections during several sampling rounds in the late 1990s. This sampling and consultations with the Ohio Department of Agriculture regarding its pesticide sampling results, suggests that further pesticide data collection is not cost-effective for the AGWQMP for the parameters that the Ohio EPA lab analyzes. In 2011 and 2012 ambient samplers collected samples for pesticide analysis for analysis of over 130 pesticides and degradation products by the U.S. Department of Agriculture. A preliminary review of the data supports the conclusion that the glacial till provides protection for Ohio's ground waters based on low detections rates and low concentrations detected (ppt results). Nevertheless, a couple of wells detected decay products of alachlor and metolachlor at ppb concentrations indicating local sensitivity.

Radiological Parameters – Radiological parameters are not included in the AGWQMP sampling.

Comparison of PWS and AGWQMP Data

Overall, we see similar trends in the PWS compliance and the AGWQMP data. This confirms that the AGWQMP data are appropriate for identifying long-term trends in the ground water quality of the major aquifers utilized by the PWSs. Thus, the AGWQMP goal of monitoring and characterizing the ground water quality utilized by PWSs in Ohio is validated by these empirical data.

It is interesting that the ground water quality differences documented between the major aquifers in AGWQMP data based on major components are not obvious in Tables M-4A and M-4B. The major elements or components (Ca, Mg, Cl, Na, K, sulfate and alkalinity) are generally the parameters utilized to identify water types. However, Ca, Mg, K and alkalinity do not have MCLs or SMCLs. So MCL and SMCL comparisons are limited in their capacity to delineate geochemical differences among waters from different aquifers. Chloride and sulfate do have SMCLs and exhibit significant differences between the major aquifers as noted above in Tables 4A and 4B. Treatment, such as softening, of PWS-distributed water can mask differences in water quality between major aquifers.

The most recognizable geochemical differences between the major aquifers in Ohio relate to the concentrations of calcium, magnesium, bicarbonate and strontium. These differences relate to the higher solubility of carbonate rocks and the long water-rock reaction time of ground water. The carbonate waters are characterized by elevated calcium, manganese, bicarbonate, and strontium compared to water in sandstone and sand and gravel aquifers. The higher percentages of PWSs that exhibit watch list and impaired category results for TDS and sulfate in the carbonate aquifers reflects the dissolution of gypsum within the carbonate stratigraphy. Summary data from the AGWQMP are presented in the appendices:

- Appendix A – AGWQMP Data Summary by Aquifer Type, includes calculated data from all current active wells (means of individual sample results);
- Appendix B - AGWQMP Inorganic Constituent Box and Whisker Plots that were developed plotting means of individual sites.

Table M-4B. Counts of wells where 2003-2013 decadal mean values of AGWQMP data occur in the Watch List and Impaired Category (maximum values used for nitrate).

Chemical Group	Chemical	Standard Type	Standard	Major Aquifer	Ambient GW Quality Wells — Raw Water		
					Total # Wells	Watch List > 50% to 100% MCL	Impaired > MCL
Inorganic Parameters	Antimony	MCL	6 µg/L	Sand & Gravel	nda	nda	nda
				Sandstone	1		
				Carbonate	nda	nda	nda
	Arsenic	MCL	10 µg/L	Sand & Gravel	172	26	27
				Sandstone	42	4	2
				Carbonate	58	9	6
	Barium	MCL	2 mg/L	Sand & Gravel	172	2	
				Sandstone	42	1	
				Carbonate	58		
Inorganic Parameters	Cadmium	MCL	5 µg/L	Sand & Gravel	172	1	1
				Sandstone	42		
				Carbonate	58		
	Chloride	SMCL	250 mg/L	Sand & Gravel	172	5	1
				Sandstone	42	2	1
				Carbonate	58	1	1
	Chromium	MCL	0.1 mg/L	Sand & Gravel	172		
				Sandstone	42		
				Carbonate	58		
	Fluoride	MCL	4 mg/L	Sand & Gravel	172	1	
				Sandstone	42		
				Carbonate	58	4	
	Iron	SMCL	0.3 mg/L	Sand & Gravel	172	17	118
				Sandstone	42	3	29
				Carbonate	58	13	9
	Manganese	SMCL	0.05 mg/L	Sand & Gravel	172	27	118
				Sandstone	42	3	29
				Carbonate	58	13	9
Inorganic Parameters	Nitrate * (max values)	MCL	10 mg/L	Sand & Gravel	172	13	1
				Sandstone	42		
				Carbonate	58	2	
	Selenium	MCL	50 µg/L	Sand & Gravel	172		
				Sandstone	41		
				Carbonate	56		
	Solids, Total Dissolved	SMCL	500 mg/L	Sand & Gravel	133	79	31
				Sandstone	47	25	11
				Carbonate	36	23	8
	Sulfate	SMCL	250 mg/L	Sand & Gravel	172	15	1
				Sandstone	42	2	3
				Carbonate	58	11	24

Chemical Group	Chemical	Standard Type	Standard	Major Aquifer	Ambient GW Quality Wells — Raw Water: Total # Wells	Watch List > 50% to 100% MCL	Impaired > MCL
	Zinc	SMCL	5.0 mg/L	Sand & Gravel	172	1	
				Sandstone	42		
				Carbonate	58		
Volatile Organic Chemicals	1,2-Dichloro-ethane	MCL	5 µg/L	Sand & Gravel	166		
				Sandstone	41		
				Carbonate	56		
	1,1-Dichloro-ethylene	MCL	7 µg/L	Sand & Gravel	166		
				Sandstone	41		
				Carbonate	56		
Volatile Organic Chemicals	1,2-Dichloro-propane	MCL	5 µg/L	Sand & Gravel	166		
				Sandstone	41		
				Carbonate	56		
	Benzene	MCL	5 µg/L	Sand & Gravel	166		
				Sandstone	41		
				Carbonate	56		
	Carbon Tetrachloride	MCL	5 µg/L	Sand & Gravel	166		
				Sandstone	41		
				Carbonate	56		
	Cis-1,2-Di-chloroethylene	MCL	70 µg/L	Sand & Gravel	166		
				Sandstone	41		
				Carbonate	56		
	Dichloro-methane	MCL	5 µg/L	Sand & Gravel	166		
				Sandstone	41		
				Carbonate	56		
	Styrene	MCL	0.1 mg/L	Sand & Gravel	166		
				Sandstone	41		
				Carbonate	56		
Volatile Organic Chemicals	Tetrachloro-ethylene	MCL	5 µg/L	Sand & Gravel	166		
				Sandstone	41		
				Carbonate	56		
	Trichloro-ethylene	MCL	5 µg/L	Sand & Gravel	166		
				Sandstone	41		
				Carbonate	56		1
	Vinyl Chloride	SMCL	2 µg/L	Sand & Gravel	166	5	1
				Sandstone	41		
				Carbonate	56	1	
Pesticides	Alachor	MCL	2 µg/L	Sand & Gravel	15		
				Sandstone	4		
				Carbonate	4		
	Atrazine	MCL	3 µg/L	Sand & Gravel	16		
				Sandstone	2		
				Carbonate	1		

Chemical Group	Chemical	Standard Type	Standard	Major Aquifer	Ambient GW Quality Wells		
					Raw Water		
					Total # Wells	Watch List > 50% to 100% MCL	Impaired > MCL
	Simazine	MCL	4 µg/L	Sand & Gravel	16		
				Sandstone	2		
				Carbonate	4		

nda Indicates no data available
Blank spaces indicate no wells exceed the standards (zeros left out to emphasize impacted wells).
* Numbers for nitrate and nitrite are based on maximum values to reflect the acute nature of contaminant.
** MCL is for combined Radium 226 and Radium 228

M7. Ground Water-Surface Water Interaction

DDAGW special studies generally focus on water quality impacts in ground water associated with recharge in sensitive geologic settings. Thus, special studies provide information on the ground water-surface water (GW-SW) interaction related to surface water recharge and contaminants transported with recharge. Two projects completed in 2012 - 2013 and one ongoing project document elements of the GW-SW interaction. Brief summaries of these studies are provided below.

Spreading of salt on roads causes ground water quality impacts, but the greater impact appears to be associated with salt storage. Over the past two years, Ohio EPA has documented impacts to ground water at several salt storage facilities including some in drinking water source protection areas. A wellfield was lost to chloride contamination at Camden in 2010. Eighty-one (81) salt storage piles were identified in or near drinking water source protection areas with 62 of these located in sensitive aquifers settings. Visual inspection was completed at all 81 sites, and most had adequate covering and pads and appeared to be managed fairly well. The ten sites considered most likely to be a source of ground water contamination were selected for additional investigation. Leaching of brine from salt piles was documented at two sites, which led to changes in salt pile management procedures. In addition to addressing these specific sites, Ohio is exploring ways to encourage implementation of BMPs. Alternative chemicals like acetate-based deicers in combination with reduced salt usage are being promoted in pollution prevention programs. A workgroup, consisting of members from the Ohio Water Resources Council, the State Coordinating Committee on Ground Water and some external stakeholders developed *Recommendations for Salt Storage: Guidance for Protecting Ohio's Water Resources*, located on the web at: http://www.ohiodnr.com/Portals/23/pdf/OWRC%20Salt%20Storage%20Guidance.pdf.

The second project was the development of Hydrogeologic Sensitivity Assessment (HSA) guidance for evaluating the pathogen sensitivity of PWSs that have detected pathogen indicators in their source water. The HSA is a flexible approach, using all available data, to identify the recharge pathways and the hydrogeologic barriers the recharge must pass through to evaluate the probability that a local aquifer will be contaminated by pathogens. Ground Water Rule implementation utilizes the HSA procedures to help identify appropriate corrective actions. Pathogens can be removed by filtration processes and, thus, their migration is different from dissolved components, such as nitrate. The consideration of the recharge pathways and transport of surface contaminants to ground water requires thought about surface water-ground water interaction and our general knowledge of this interaction was critical to developing the HSA procedures. Likewise, the application of the HSA tool to evaluate hydrogeologic settings for pathogen sensitivity is generating data that identifies areas of pathogen contamination in sensitive aquifers. The Guidance for Hydrogeologic Sensitivity Assessment will be posted on the web when it is finalized.

Three ODNR observation wells were selected for ground water quality monitoring in conjunction with the water level data collected by ODNR. Pressure transducers were installed for the water level data and dedicated pumps were installed for collecting water samples. The purpose of this sampling is to evaluate correlations between static water level and water quality. Water samples have been collected monthly since June 2012. Preliminary results will be evaluated after two years of data collection and conclusions will be reported in the 2016 Integrated Report.

M8. Conclusions and Future Directions for Ground Water Protection

Ohio is fortunate that ground water is plentiful across the state. With the exceptions of a couple of areas that exhibit effects of over-pumping, decreasing static water levels have not been documented in extensive areas. Although the quantity of ground water appears stable, the documentation of water quality impacts in this document illustrate that continued protection of ground water resources is necessary. Ground water contamination can eliminate the potential use of water resources as easily as diminished quantities.

As documented in the previous sections, numerous sites exhibit ground water contamination from anthropogenic and natural point and nonpoint sources. The only alternative for natural sources of contamination that cause impairment of drinking water is to develop and install treatment that removes the contamination or to locate another water source. The alternatives for managing anthropogenic sources are more numerous, with the most constructive focusing on prevention of releases that migrate to ground water. Instituting best management practices (especially for the use of fertilizers and salt storage), implementing appropriate siting criteria for new waste storage and disposal sites, and improving design for material storage and waste disposal facilities are proactive approaches to prevent releases to ground water. These kinds of proactive practices are critical to the sustainability of Ohio's high quality ground water resources.

Generally, awareness and concern about ground water resources is increasing. State agencies are working together to develop appropriate guidance or guidelines for activities that may threaten ground water. This is documented by the development of the Recommendations for Geothermal Heating and Cooling Systems (February 2012), Recommendations for Salt Storage (February 2013), and the efforts by many agencies, but particularly ODNR, to provide information on water resource issues associated with shale gas development.

Ohio EPA - DDAGW, has completed a new database, GWQCP, to house non-compliance water quality data. The completion of this database required transfer of existing data and development of various tools and reports. Once complete, our efforts will focus on analysis of these data in conjunction with developing parameter-based technical reports, associated fact sheets, and web-based data access with simple plotting tools. The development of these reports, fact sheets, and web-based tools is important for increasing the availability of these data to the public.

The Ground Water Quality Characterization Program has matured and is due for a major evaluation. The goal of this modernization is to anticipate future water quality needs and start incorporating changes to collect additional data. A list of issues for consideration in this evaluation is provided below:

- Alignment with the National Ground Water Monitoring Network
- Increase parameter list (methane, DO, etc.);
- Change sampling interval for existing wells;
- Add wells;
  - Major aquifer types;
  - Wells in specific watersheds or stratigraphic units;
- Target sensitive wells (screens at water table surface);
- Incorporate data from up-gradient wells at compliance sites;
- Data needs for new rule development;
- Consider special studies to expand knowledge of specific processes:
  - Sampling in sensitive areas;
  - Pathogen sensitivity in unglaciated portions of State;
  - Evaluate the effectiveness of saturated casing as a hydrogeologic barrier.

Broad participation in the modernization discussions will be encouraged to maximize the potential for identifying our future data needs. This evolution of the Ground Water Quality Characterization Program will help to promote the sustainability of Ohio's ground water resources.

The ongoing implementation of the Source Water Protection Program (SWAP) for Ohio's public water systems helps raise awareness of ground water quality issues and promotes source water protection planning.   The SWAP potential contaminant source inventory data was instrumental in identifying and ranking major sources of contamination near public water systems, as listed in Table M-3 in the 2012 and 2014 Integrated Reports. SWAP staff have also had key roles in the development of the salt storage guidance and guidance for environmentally sound installation of geothermal wells. They are currently involved in updating state guidance on proper well abandonment.

Ohio's ground water resources are relatively well-protected from surface contamination due to the layer of low-permeability glacial till that overlies approximately two-thirds of the state. Long-term efforts to protect ground water quality need to focus on aquifers subject to rapid recharge from the surface, such as shallow fractured bedrock, karst bedrock, and shallow sand and gravel units.

Ground Water Section Appendices

Appendix A - AGWQMP Data Summary by Aquifer Type

Appendix B - AGWQMP Inorganic Constituent Box and Whisker Plots

Appendix A

Ambient Ground Water Quality Monitoring Program
Data Summary by Aquifer Type

Ambient ground water quality data presented in Table 1 summarizes the geochemistry by major aquifer type for all active AGWQMP wells. This table provides the arithmetic mean, median, minimum value, maximum value, standard deviation, total number of samples, number of samples below the reporting limit, and the percent non-detect for all individual inorganic and field parameter results in each aquifer type as of July 2013. The reporting limit was used for the non-detect values in calculating means and standard deviation (in some cases zeros are recorded as the reporting limit). The "non-detect" column records the percent of analyses measured below the current reporting limit (rounded to the nearest percent). The presence of a less than sign (<) in the minimum value field (column 5) indicates the minimum value is the reporting limit. The minimum value may not always coincide with the current reporting limit due to changes in analytical methods, since AGWQMP sampling started in 1973 resulting in multiple reporting limits. The estimates of the number and percentages of non-detect data (columns 8 and 9) may also be influenced by changes in the reporting limits.

The data summarized in Table 1 represents the accumulation of over 160,000 raw, inorganic ground-water data results gathered at 260 active and standby wells across Ohio over 40 years of sampling. Consistent sampling protocol, analytical procedures, and long site histories lend a unique significance to the AGWQMP data. Table 1 is the best summary available for the general water quality of Ohio's major aquifers, the source water for Ohio's public drinking water systems using ground water. It should be noted, however, that some wells in the AGWQMP network have been influenced by anthropogenic sources, such as nitrates or VOCs. Thus, the water quality presented is not pristine, but rather is typical of the ground water quality of aquifers utilized for source water by the PWSs.

The Ambient Water Quality Table is organized into four categories, identified in the first column:

- Field Parameters – measured in the field, such as pH and water temperature;
- Major Constituents – such as calcium or sulfate, concentrations in the range of mg/L (ppm);
- Trace Constituents – such as arsenic or cadmium, concentrations in range of µg/L (ppb); and
- Nutrients – components required by organic systems for growth, concentrations in mg/L (ppm).

Use of Primary and Secondary MCLs

Maximum Contaminant Levels (MCLs) are regulatory standards for permissible concentrations of parameters in drinking water delivered to the public. Secondary Maximum Contaminant Levels (SMCLs) are advisory limits applied strictly to treated water at public water systems for aesthetic water quality issues, such as taste and odor. Since AGWQMP data are obtained from raw (untreated) ground water, which is unregulated, any exceedence of an MCL or SMCL by an AGWQMP data point has no legal or regulatory consequence for a PWS. However, since MCLs and SMCLs are widely known, they represent a practical benchmark for discussion purposes. MCLs and SMCL values are included in the first column of Table 1 for parameters that have established regulatory values

Table 1 – Ambient Ground Water Quality Data

Ambient Ground Water Quality Monitoring Data Summary for Active Wells by Major Aquifer as of July 2013

FIELD PARAMETERS

MCL/ SMCL	Parameter and Units	Major Aquifer	Mean Value	Median Value	Minimum Value *	Maximum Value	Standard Deviation	Number of Samples	Number § Below Rep. Limit	Percent § Non-detect
	Oxidation-Reduction Potential (ORP) mV	Sand and Gravel	52.6	28.5	-520	815	135	1092	NA	NA
		Sandstone	100	69	-530	881	208	248	NA	NA
		Carbonate	-13.5	-19.0	-268	778	124	248	NA	NA
7.0-10.5 S.U.	pH, Field S.U.	Sand and Gravel	7.33	7.33	5.60	8.6	0.33	2972	NA	NA
		Sandstone	7.24	7.24	5.67	8.7	0.46	636	NA	NA
		Carbonate	7.22	7.19	6.20	8.7	0.31	804	NA	NA
	Specific Conductivity µmohms/cm	Sand and Gravel	710	700	195	2375	194	2320	NA	NA
		Sandstone	725	557	86	7900	586	571	NA	NA
		Carbonate	938	880	270	2070	275	610	NA	NA
500 [S] mg/L	Total Dissolved Solids, Field mg/L	Sand and Gravel	533	517	187	1726	144	1100	NA	NA
		Sandstone	520	398	57	2210	379	283	NA	NA
		Carbonate	746	692	304	1505	201	257	NA	NA
	Water Temperature Degrees C	Sand and Gravel	13.5	13.19	5.1	31.9	2.11	2030	NA	NA
		Sandstone	12.6	12.5	8.5	18.8	1.5	625	NA	NA
		Carbonate	13.2	13.0	6.9	19	1.57	794	NA	NA

MAJOR COMPONENTS

MCL/ SMCL	Parameter and Units	Major Aquifer	Mean Value	Median Value	Minimum Value * £	Maximum Value	Standard Deviation	Number of Samples	Number Below Rep. Limit	Percent Non-detect
	Alkalinity, Total as CaCO3 mg/L	Sand and Gravel	264	267	<5.0	775	67.9	3440	6	0
		Sandstone	197	196	<5.0	1500	115	745	1	0
		Carbonate	306	300	92.6	642	67.1	886	0	1
	Calcium, Total mg/L	Sand and Gravel	93.1	94	<2.0	300	24.1	3494	1	0
		Sandstone	59.4	58	<2.0	167	30.6	754	7	1
		Carbonate	123	114	26	255	36.0	898	0	0

MCL/ SMCL	Parameter and Units	Major Aquifer	Mean Value	Median Value	Minimum Value * £	Maximum Value	Standard Deviation	Number of Samples	Number Below Rep. Limit	Percent Non-detect
250 [S] mg/L	Chloride mg/L	Sand and Gravel	39.6	32	<2.0	474	32.9	3476	102	3
		Sandstone	49.5	31	<2.0	494	61.3	749	61	8
		Carbonate	28.4	15.7	<2.0	420	36.4	881	80	9
	Hardness, Total as CaCO3 mg/L	Sand and Gravel	348	352	<10.0	953	85.6	3025	2	0
		Sandstone	223	212	<10.0	716	113	679	1	0
		Carbonate	504	449	110	956	159	787	0	0
	Magnesium, Total mg/L	Sand and Gravel	28.3	29	<1.0	81	9.5	3494	9	0
		Sandstone	17.9	17	<1.0	80	10.8	754	9	1
		Carbonate	49.5	43	11	106	18.3	899	0	0
	Potassium, Total mg/L	Sand and Gravel	2.37	2.0	<0.9	17	0.99	3381	848	25
		Sandstone	2.39	2.0	<1.0	8.0	0.86	743	242	33
		Carbonate	2.81	2.0	<1.3	8.4	1.17	874	84	10
	Sodium, Total mg/L	Sand and Gravel	26.1	22	<4.0	427	20.1	3496	96	3
		Sandstone	72.2	29	<5.0	824	108	754	40	5
		Carbonate	35.4	27	<5.0	239	27.4	898	16	2
250 [S] mg/L	Sulfate mg/L	Sand and Gravel	76.2	66	<5.0	640	46.1	3479	25	1
		Sandstone	82.5	43.1	<5.0	1320	166	751	98	13
		Carbonate	240	173	<5.0	1000	199	899	1	0
500 [S] mg/L	Total Dissolved Solids mg/L	Sand and Gravel	459	450	<10.0	2120	118	3399	1	0
		Sandstone	441	338	54	2390	344	742	0	0
		Carbonate	718	638	324	3200	267	874	0	0

TRACE CONSTITUENTS

MCL/ SMCL	Parameter and Units	Major Aquifer	Mean Value	Median Value	Minimum Value * £	Maximum Value	Standard Deviation	Number of Samples	Number Below Rep. Limit	Percent Non-detect
50-200[S] µg/L	Aluminum µg/L	Sand and Gravel	202	<200	<200	2880	57.8	2914	2908	100
		Sandstone	201	<200	<200	448	11.1	701	697	99
		Carbonate	207	<200	<200	2050	93.5	746	739	99
10 µg/L	Arsenic, Total µg/L	Sand and Gravel	5.59	<2.0	<2.0	102	8.79	3351	1668	50
		Sandstone	2.51	<2.0	<2.0	78	3.24	736	605	82
		Carbonate	3.72	<2.0	<2.0	25.7	3.61	883	503	57
2000 µg/L	Barium µg/L	Sand and Gravel	158	119	<15.0	2160	179	3320	39	1
		Sandstone	215	73	<15.0	2120	411	728	100	14
		Carbonate	73.7	46	<7.0	568	69.9	879	78	9

MCL/ SMCL	Parameter and Units	Major Aquifer	Mean Value	Median Value	Minimum Value * £	Maximum Value	Standard Deviation	Number of Samples	Number Below Rep. Limit	Percent Non-detect
	Bromide µg/L	Sand and Gravel	149	60.7	<20	1680	111	814	93	11
		Sandstone	144	51.6	<20	1300	239	209	38	18
		Carbonate	87.8	100	<20	920	179	181	38	21
5 µg/L	Cadmium, Total µg/L	Sand and Gravel	0.17	<0.2	0	3.2	0.11	3139	3112	99
		Sandstone	0.19	<0.2	0	18.8	0.69	737	728	99
		Carbonate	0.18	<0.2	0	1.6	0.10	863	847	98
100 µg/L	Chromium, Total µg/L	Sand and Gravel	22.1	<30	<2.0	50	12.6	3184	3168	99
		Sandstone	21.4	<30	<2.0	30	12.9	744	742	100
		Carbonate	23.5	<30	<2.0	50	11.8	865	851	98
1300 ^{AL} µg/L	Copper µg/L	Sand and Gravel	11.0	<10	<2.0	405	17.5	3009	2200	73
		Sandstone	13.7	<10	<2.0	235	23.4	726	486	67
		Carbonate	16.3	<10	<2.0	586	46.0	770	499	65
4 mg/L 2^{S} mg/L	Fluoride mg/L	Sand and Gravel	0.40	0.25	0	3.04	0.4	2812	845	30
		Sandstone	0.32	0.25	<0.10	1.18	0.17	697	164	24
		Carbonate	1.35	1.35	<0.10	3.58	0.62	736	19	3
300 ^{S} µg/L	Iron, Total µg/L	Sand and Gravel	1183	708	<20	29700	1419	3488	707	20
		Sandstone	1446	376	<50	34600	3386	752	160	21
		Carbonate	1102	810	<50	27300	1644	901	81	9
15 ^{AL} µg/L	Lead, Total µg/L	Sand and Gravel	4.51	<2.0	<1.0	2710	58.3	3488	3055	91
		Sandstone	2.96	<2.0	<2.0	164	7.32	742	633	89
		Carbonate	3.18	<2.0	<2.0	167	8.65	852	733	86
50 ^{S} µg/L	Manganese, Total µg/L	Sand and Gravel	191	120	<8.0	5130	223	3422	467	14
		Sandstone	225	99	<9.0	2220	351	747	132	18
		Carbonate	31.9	17	<10	300	34.2	875	225	26
	Nickel, Total µg/L	Sand and Gravel	29.0	<40	<1.0	269	17.8	2969	2380	80
		Sandstone	28.8	<40	<2.0	175	8.15	711	619	87
		Carbonate	30.8	<40	<2.0	88	16.1	769	603	78
50 µg/L	Selenium, Total µg/L	Sand and Gravel	2.03	<2.00	<2.00	10.9	0.38	3039	2944	97
		Sandstone	2.02	<2.00	<2.00	5.5	0.21	730	712	98
		Carbonate	2.03	<2.00	<2.00	5.0	0.22	766	737	96
	Strontium, Total µg/L	Sand and Gravel	1957	371	<30	36400	4542	2965	4	0
		Sandstone	544	375	<30	5740	759	709	19	3
		Carbonate	16367	14700	<30	51600	11154	767	2	0

MCL/ SMCL	Parameter and Units	Major Aquifer	Mean Value	Median Value	Minimum Value * £	Maximum Value	Standard Deviation	Number of Samples	Number Below Rep. Limit	Percent Non-detect
5000 S µg/L	Zinc, Total µg/L	Sand and Gravel	20.3	<10	<6.0	1860	55.3	3028	2059	68
		Sandstone	30.8	10	<10	902	57.2	725	349	48
		Carbonate	71.8	11	<10	4090	265	770	354	46
NUTRIENTS										
MCL/ SMCL	**Parameter and Units**	**Major Aquifer**	**Mean Value**	**Median Value**	**Minimum Value * £**	**Maximum Value**	**Standard Deviation**	**Number of Samples**	**Number Below Rep. Limit**	**Percent Non-detect**
	Ammonia mg/L	Sand and Gravel	0.22	0.08	0	3.41	0.36	3449	1390	40
		Sandstone	0.37	0.17	0	2.30	0.49	744	210	29
		Carbonate	0.41	0.35	0	5.93	0.50	890	96	11
	Chemical Oxygen Demand mg/L	Sand and Gravel	13.3	<10	<2.0	200	9.25	3391	3085	91
		Sandstone	13.4	<10	<6.0	172	8.43	734	689	94
		Carbonate	14.0	<10	<10	371	16.1	888	754	85
10 mg/L	Nitrite & Nitrate NO2 +NO3 as N mg/L	Sand and Gravel	0.73	<0.10	0	12.3	1.27	3346	1857	55
		Sandstone	0.41	<0.10	0	4.32	0.82	734	539	73
		Carbonate	0.25	<0.10	0	7.38	0.85	872	764	88
	Phosphorus mg/L	Sand and Gravel	0.32	<0.05	0	810	14.4	3154	2183	69
		Sandstone	0.09	0.05	0	4.4	0.26	695	319	46
		Carbonate	0.05	<0.05	0	4.37	0.17	819	524	69
	Total Kjeldahl N mg/L	Sand and Gravel	0.37	0.24	0	4.49	0.40	2323	959	41
		Sandstone	0.52	0.29	0	6.75	0.61	587	221	38
		Carbonate	0.55	0.44	0	7.04	0.59	596	116	19
	Total Organic Carbon mg/L	Sand and Gravel	2.42	<2.0	<0.5	62	2.72	3026	2732	90
		Sandstone	2.35	<2.0	<0.5	57	2.97	698	635	91
		Carbonate	2.61	<2.0	<2.0	73	4.50	778	667	86

Appendix B

Ambient Ground Water Quality Monitoring Program
Inorganic Constituent Box and Whisker Plots

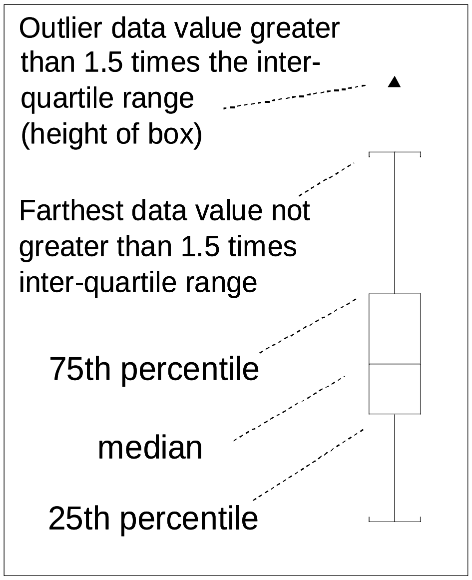
This document provides a concise graphical summary, in box and whisker plot format, of the Ambient Ground Water Quality Monitoring Program (AGWMP) inorganic data set as of July 1, 2013. The Box and Whisker plots from the Ambient Ground Water Quality Network database include results from some 5500 raw (untreated), inorganic water samples collected over the past 30 years across 260 active and standby wells in Ohio. Active (AGWMP) wells are sampled every six or eighteen months. The primary objective of collecting statewide, raw ground water data from major aquifers is to characterize Ohio's ground water quality, which in turn is used to enhance water resource planning and to prioritize ground water protection activities. The Ambient Ground Water Monitoring Program places a priority on collecting water quality data representative of aquifers used by public water systems. Analysis of water quality changes in space and time indicate that some of the AGWMP wells are influenced by land use activities. The Ambient wells are considered typical of the local ground water used as source water for public water systems.

In the following box plots, the inorganic water-quality sample results (calculated means for each well) are plotted on the Y-axis, while the X-axis represents the three major aquifer groupings within Ohio (sand and gravel, sandstone, and carbonate). These box plots allow the reader to effectively compare data variability across major aquifer types, and are presented in the same order and groupings as in Table 1 in Appendix A: Field Parameters, Major Constituents, Trace Constituents, and Nutrients. The number of wells (mean of data results for each well) used to construct each group's box plot, and the percent of well means below the reporting limit are indicated above the major aquifer labels on the x-axis.

In some cases, the Y-Axis is presented in log scale to enhance readability of the plots. Box plots which appear without "boxes" (common in Trace Elements section) have too little data variability to generate visible 25th and 75th percentiles of the distribution (upper and lower box bounds). In these cases, the boxes appear collapsed to the most common data point, typically the Reporting Limit. These collapsed boxes generally occur when the "Percent Non-Detect" column of Table 1 is greater than 75%, indicating that the bulk of the data set was reported below the detection limit. Construction details for a box plot are found on the following page of this report.

Ground Water Quality Characterization Program
Division of Drinking and Ground Waters
50 West Town Street, Suite 700
Columbus, OH 43215
(614) 644-2752
Web Page: http://www.epa.state.oh.us/ddagw/wqcharpr.html
Email: gwq@epa.state.oh.us

Box and Whisker Plots

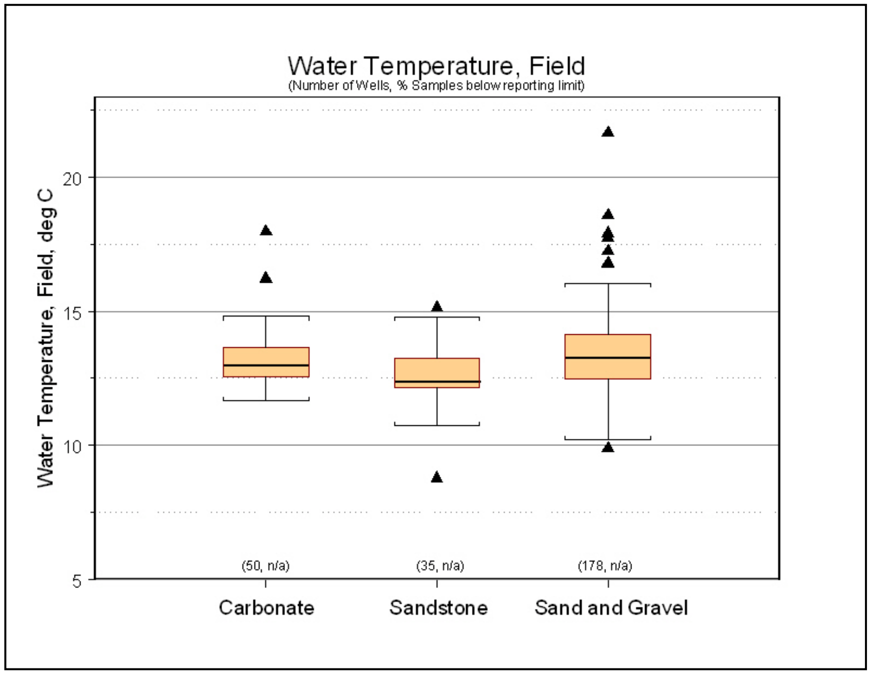


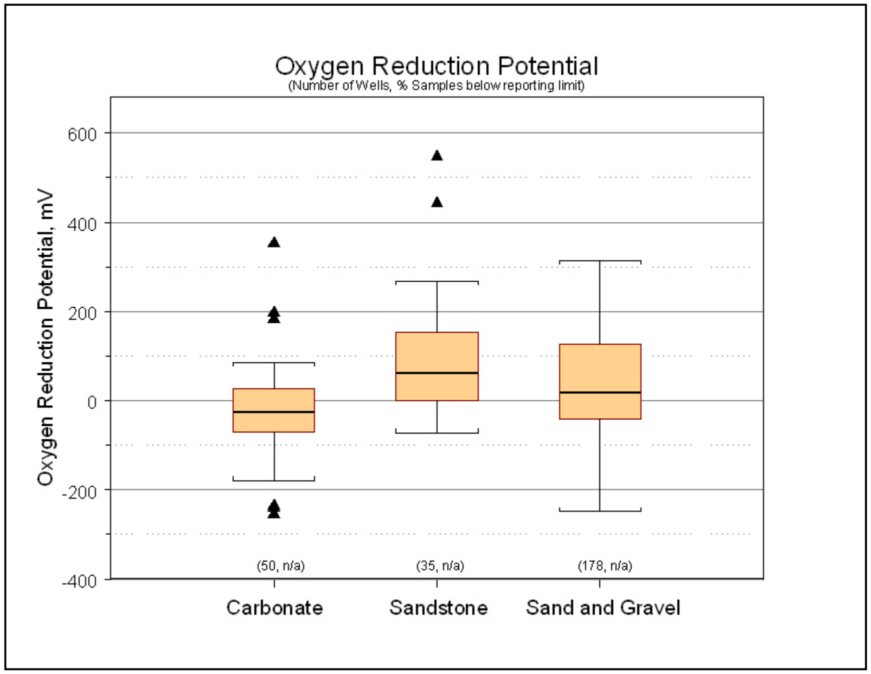
Box and Whisker Plots are an efficient graphical method for displaying the distribution of a data set. The format allows easy comparison of one distribution to those of other groups of data. The "box" itself outlines the range of half the data (the 25th to 75th percentiles, called the Inter-Quartile Range, or IQR). The median of the data set (the 50th percentile) is indicated by a horizontal bar inside the box.

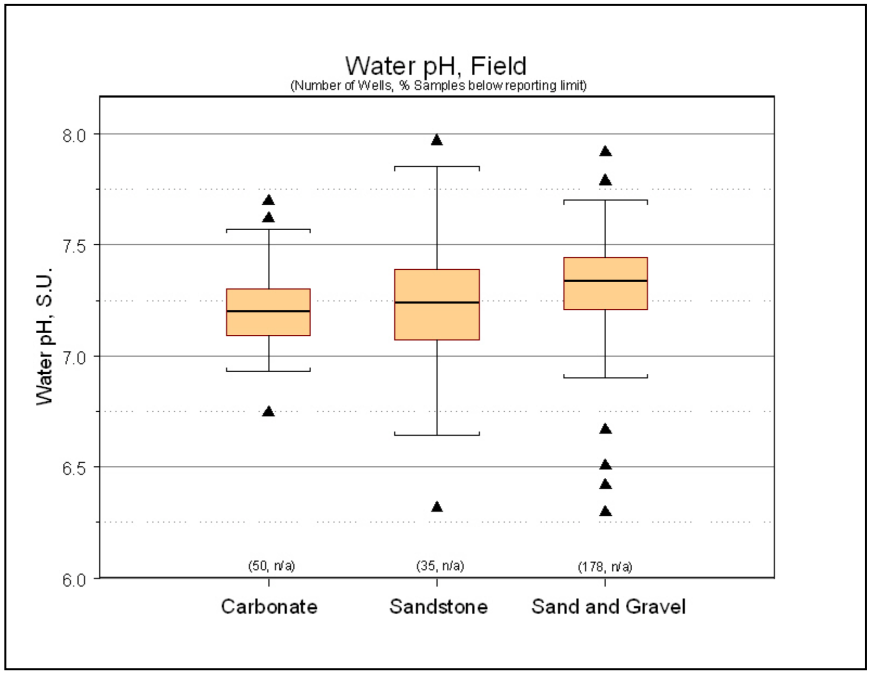
The whiskers are vertical lines extending from the top and bottom of the box, and indicate the range of data (which are not outliers) above and below the 75th and the 25th percentiles, respectively. The whisker caps (horizontal bars at the ends of the whiskers) indicate the last data point which does not exceed 1.5 times the IQR. Outliers exceed this limit and are identified by individual symbols above or below the whisker caps.

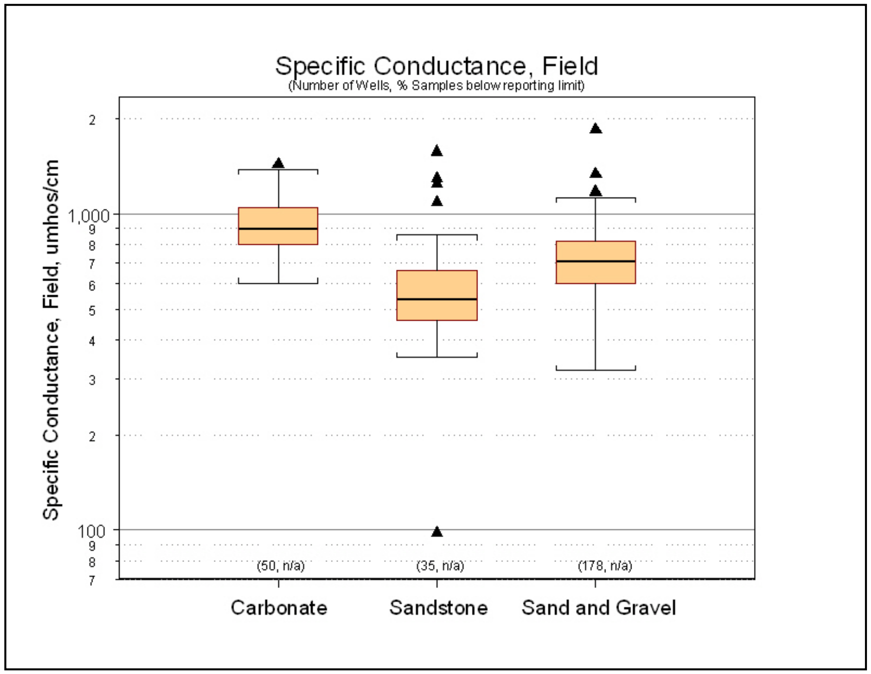
A normally distributed data set is generally indicated if the median bar is located mid-way between the top and bottom of the box. A skewed data set would have the median bar either closer to the 25th percentile (positively skewed) or to the 75th percentile (negatively skewed).

Field Parameters








Specific Conductance, Field
(Number of Wells, % Samples below reporting limit)
Specific Conductance, Field, umhos/cm
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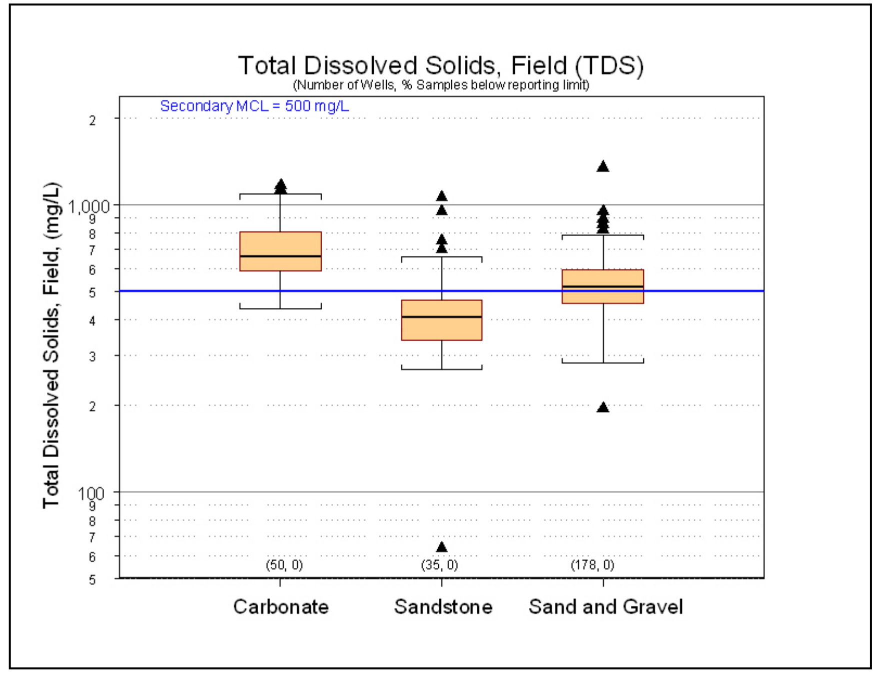
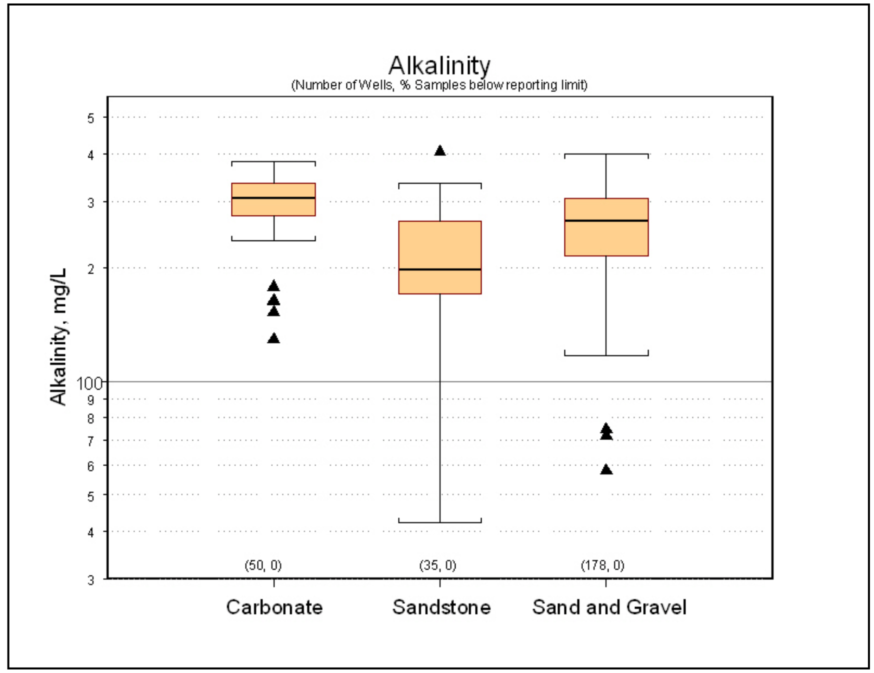
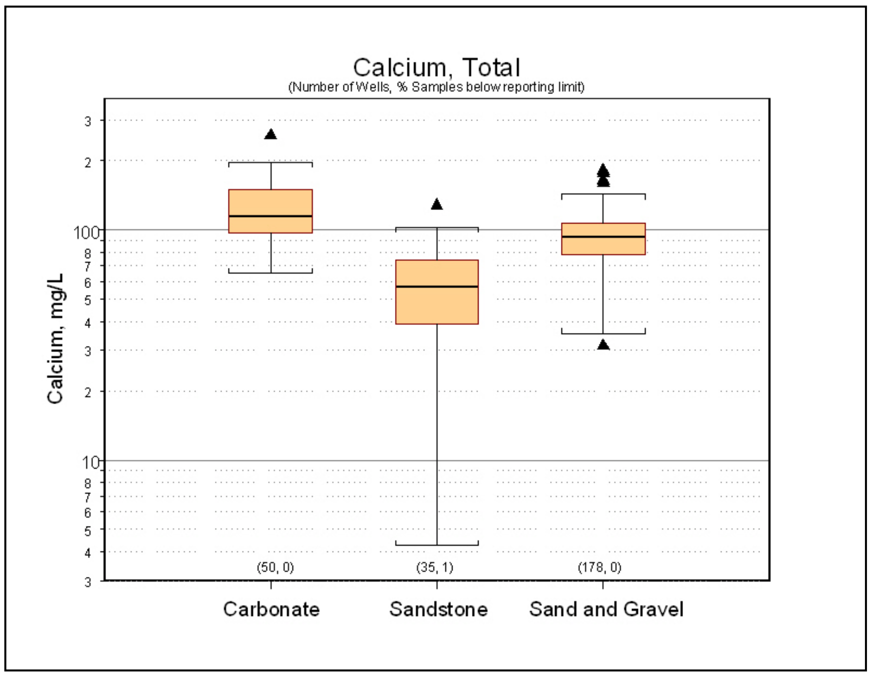
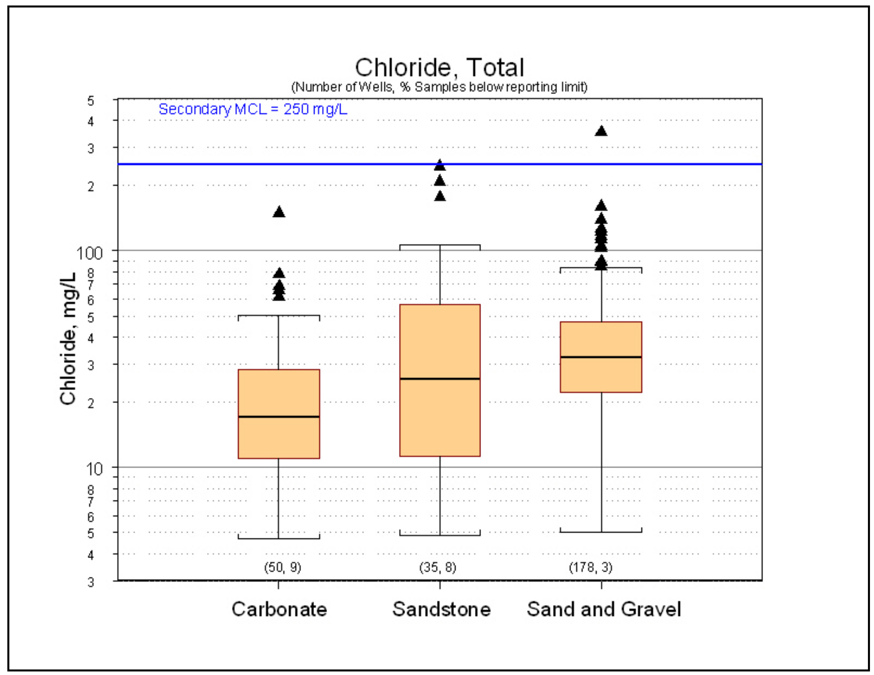
100
(50, n/a)
(35, n/a)
(178, n/a)
Carbonate
Sandstone
Sand and Gravel

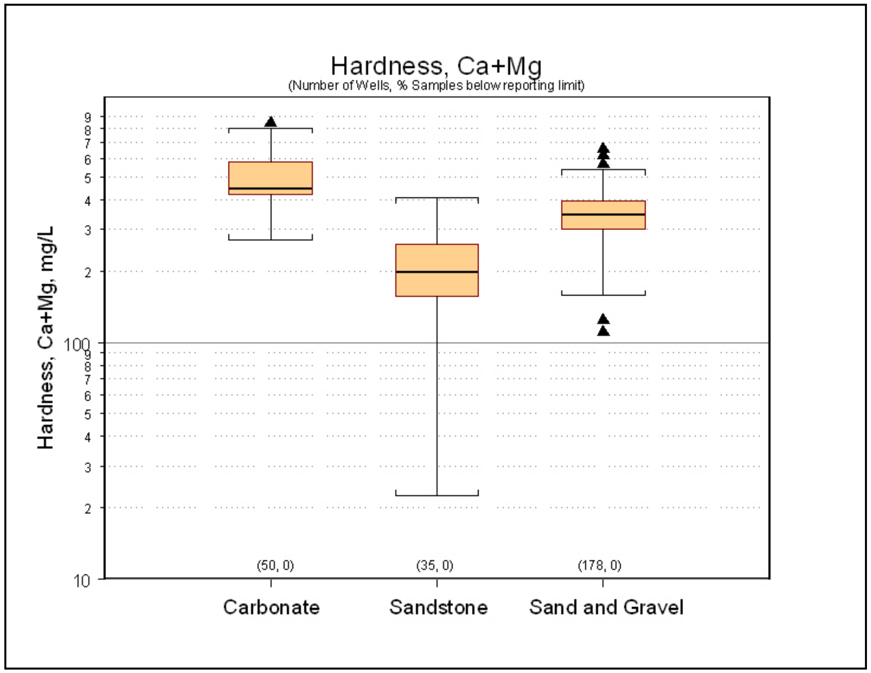

Total Dissolved Solids, Field (TDS)
(Number of Wells, % Samples below reporting limit)
Secondary MCL = 500 mg/L
Total Dissolved Solids, Field, (mg/L)
1,000
100
(50, 0)
(35, 0)
(178, 0)
Carbonate
Sandstone
Sand and Gravel

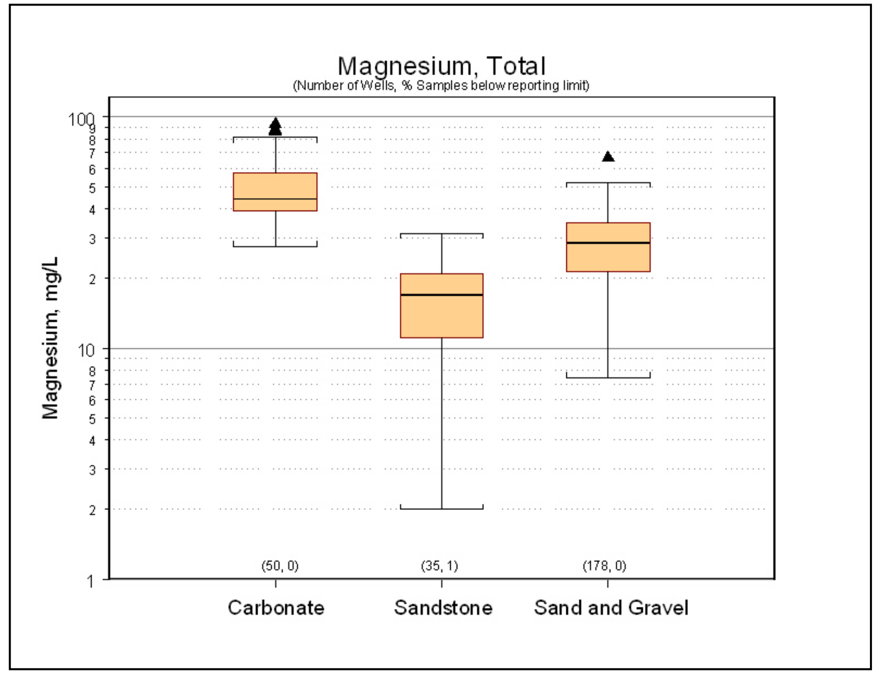
Major Constituents








Hardness, Ca+Mg
(Number of Wells, % Samples below reporting limit)
Hardness, Ca+Mg, mg/L
10
100
(50, 0)
(35, 0)
(178, 0)
Carbonate
Sandstone
Sand and Gravel


Magnesium, Total
(Number of Wells, % Samples below reporting limit)
Magnesium, mg/L
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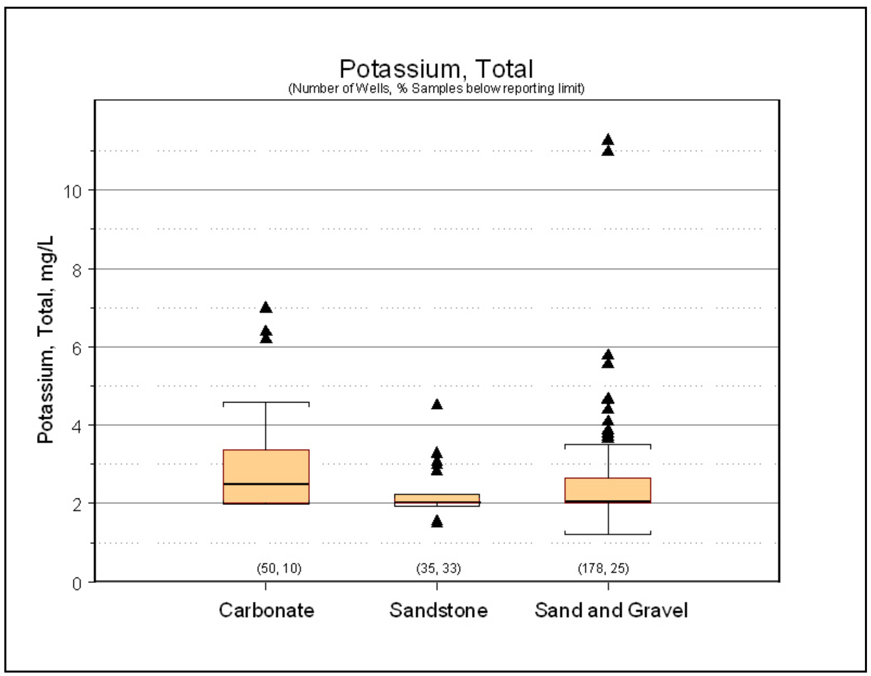
10
100
(50, 0)
(35, 1)
(178, 0)
Carbonate
Sandstone
Sand and Gravel


Potassium, Total
(Number of Wells, % Samples below reporting limit)
Potassium, Total, mg/L
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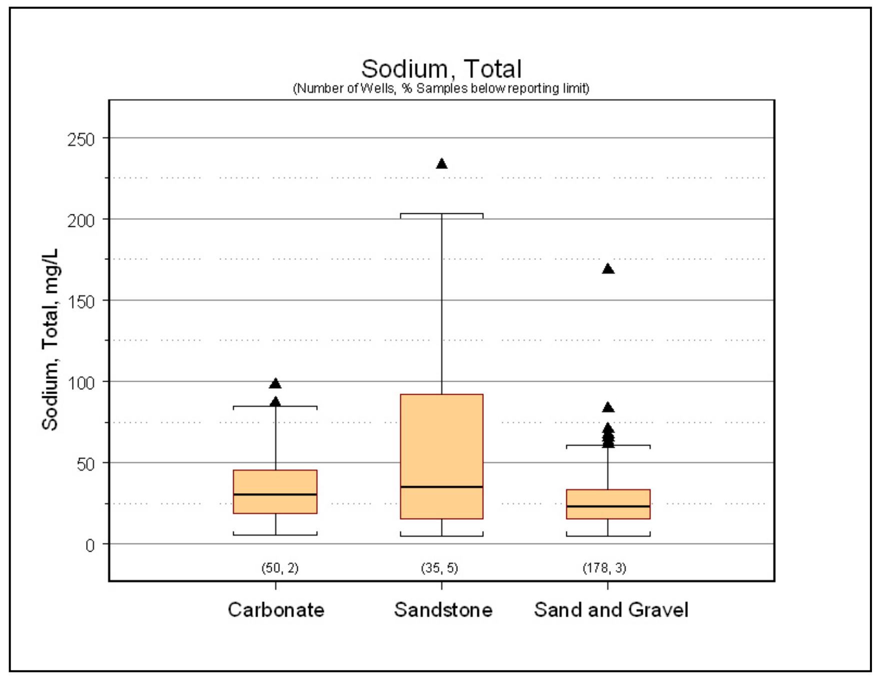
2
4
6
8
10
(50, 10)
(35, 33)
(178, 25)
Carbonate
Sandstone
Sand and Gravel


Sodium, Total
(Number of Wells, % Samples below reporting limit)
Sodium, Total, mg/L
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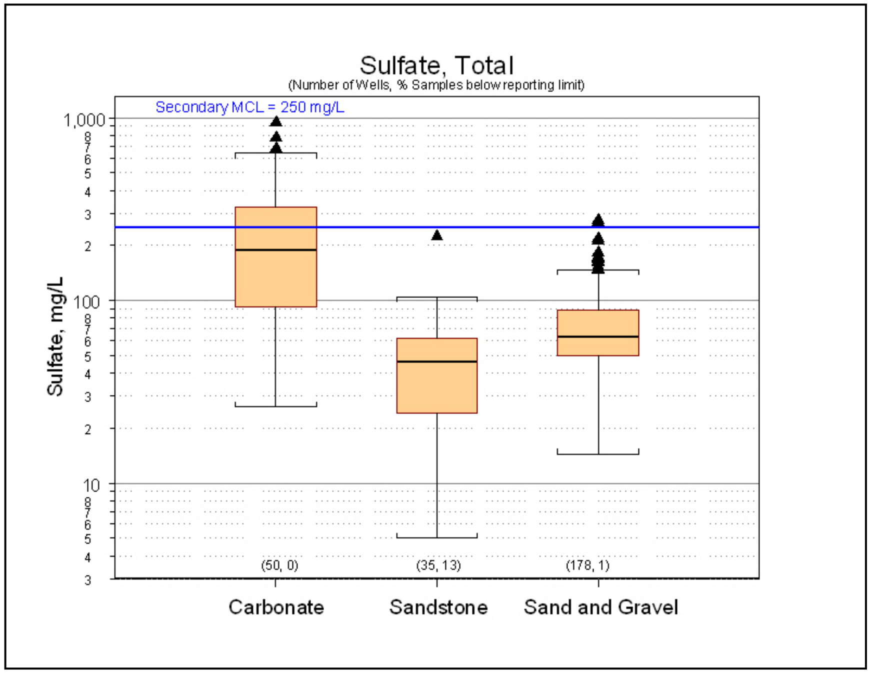
50
100
150
200
250
(50, 2)
(35, 5)
(178, 3)
Carbonate
Sandstone
Sand and Gravel


Sulfate, Total
(Number of Wells, % Samples below reporting limit)
Secondary MCL = 250 mg/L
Sulfate, mg/L
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100
10
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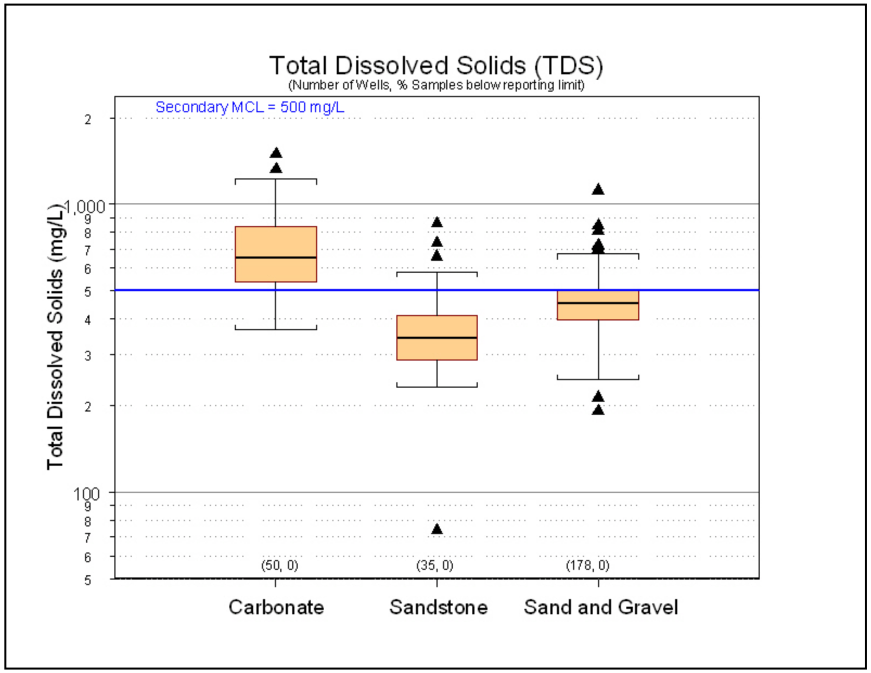
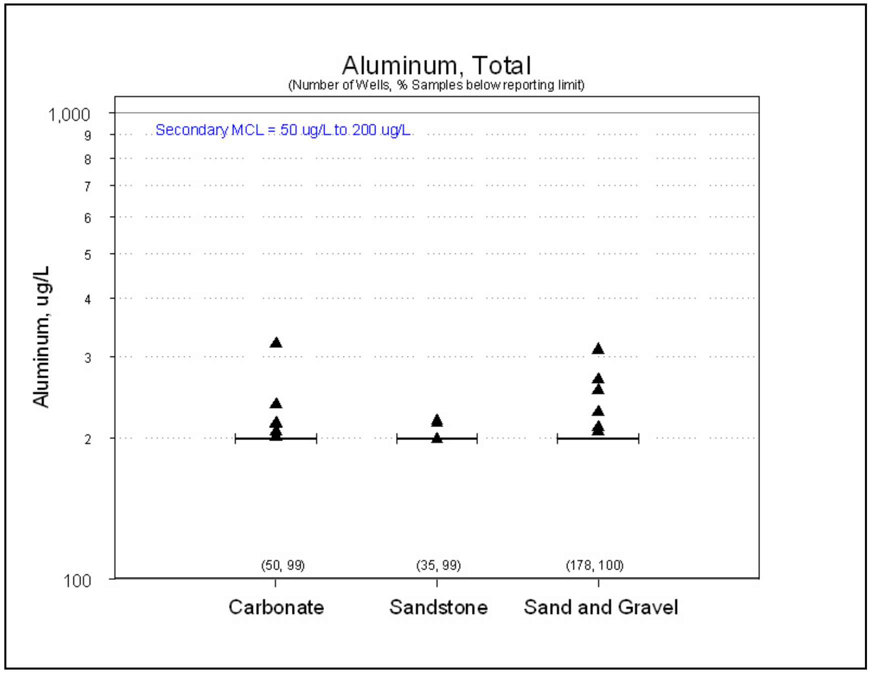
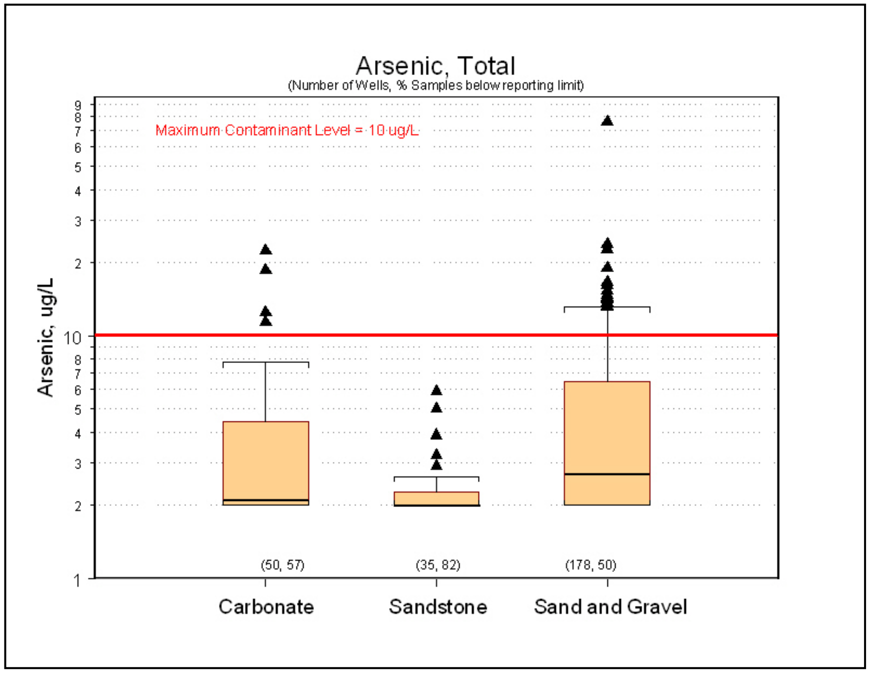
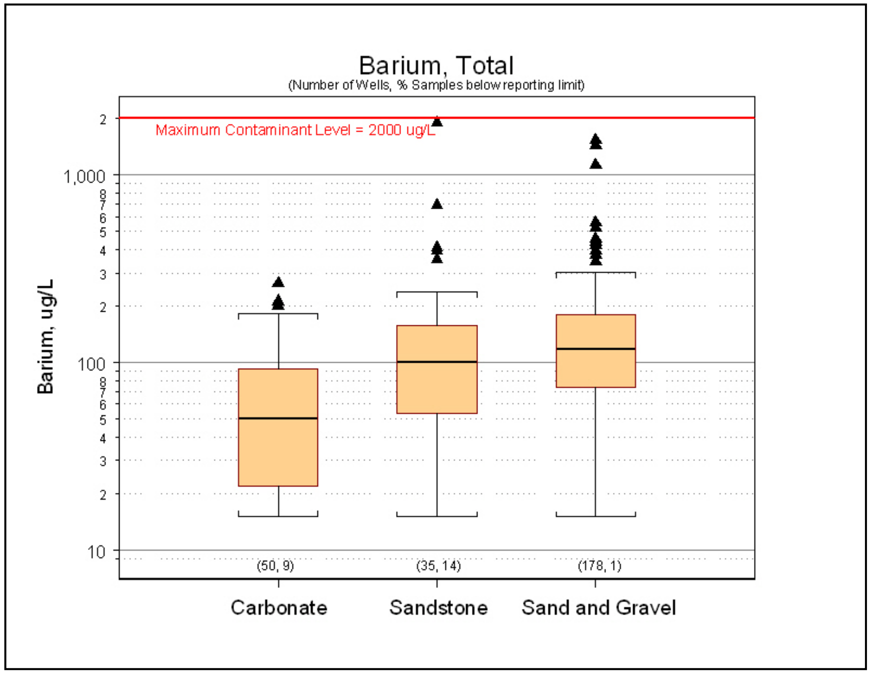
(35, 13)
(178, 1)
Carbonate
Sandstone
Sand and Gravel

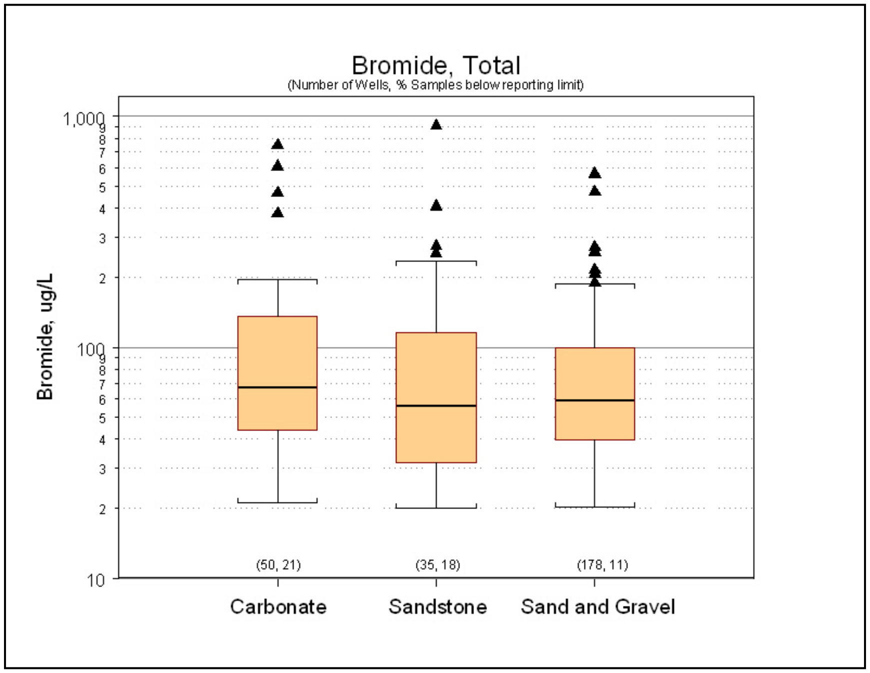

Total Dissolved Solids (TDS)
(Number of Wells, % Samples below reporting limit)
Secondary MCL = 500 mg/L
Total Dissolved Solids (mg/L)
1,000
100
(50, 0)
(35, 0)
(178, 0)
Carbonate
Sandstone
Sand and Gravel

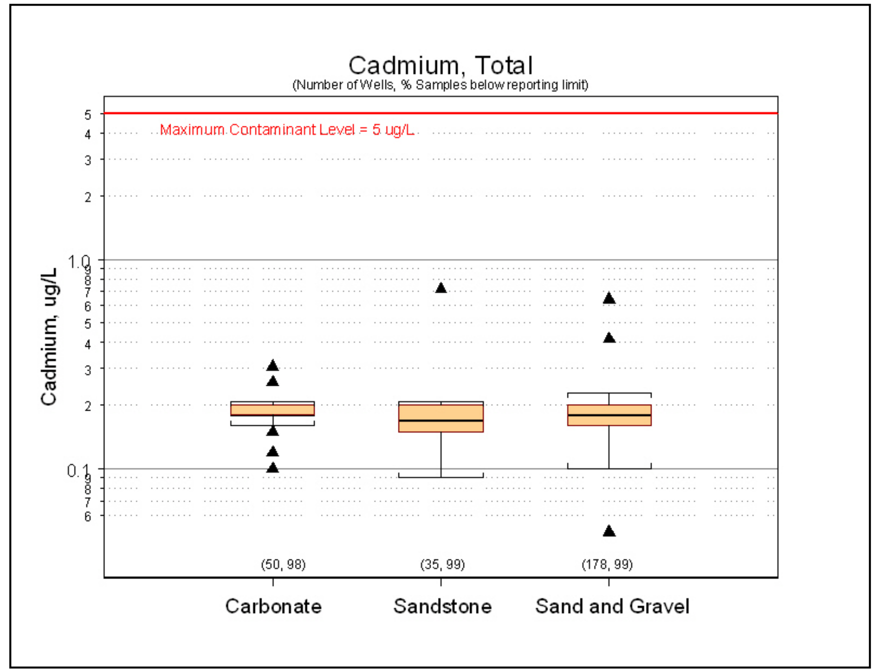
Trace Constituents

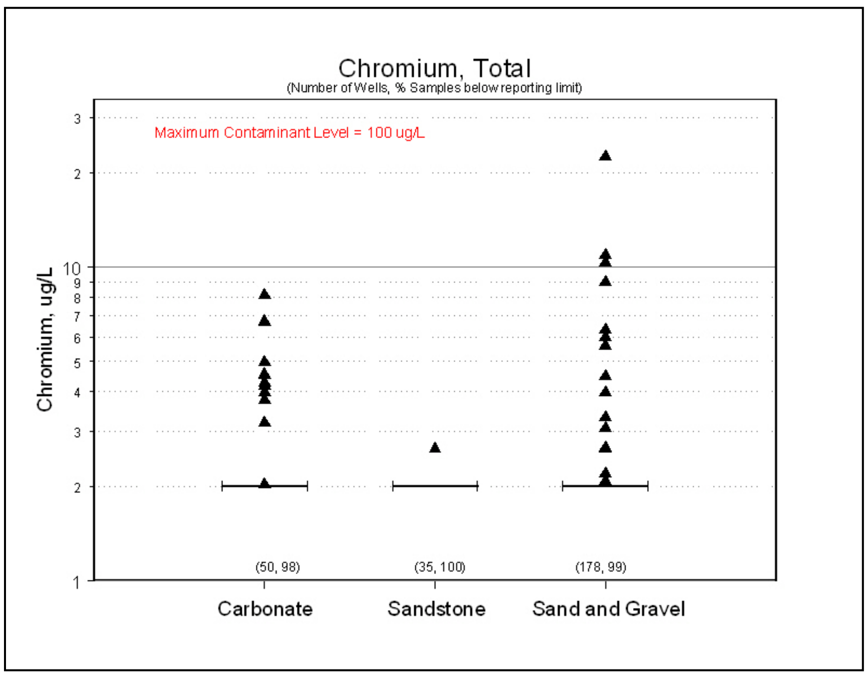


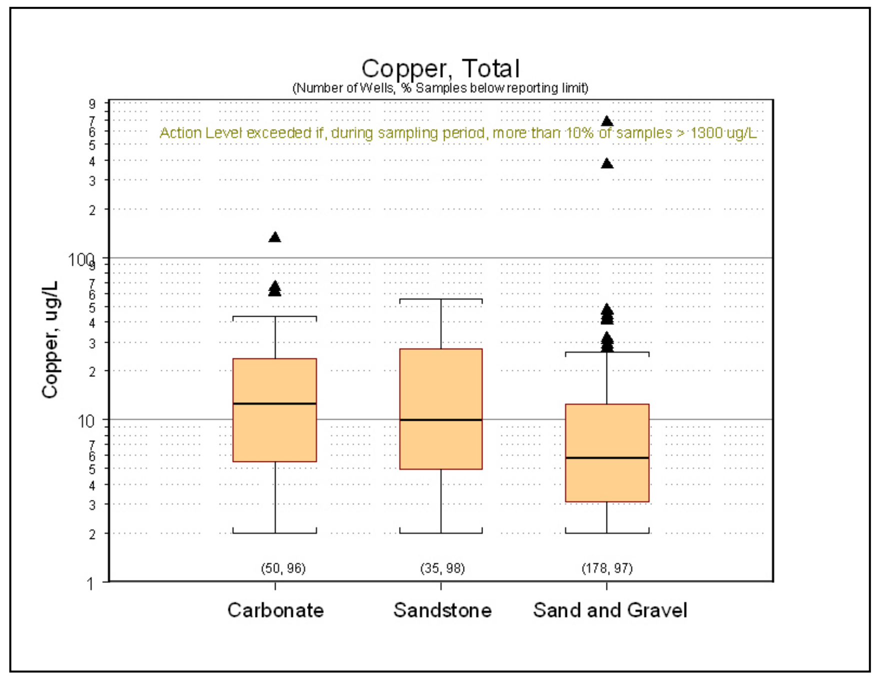


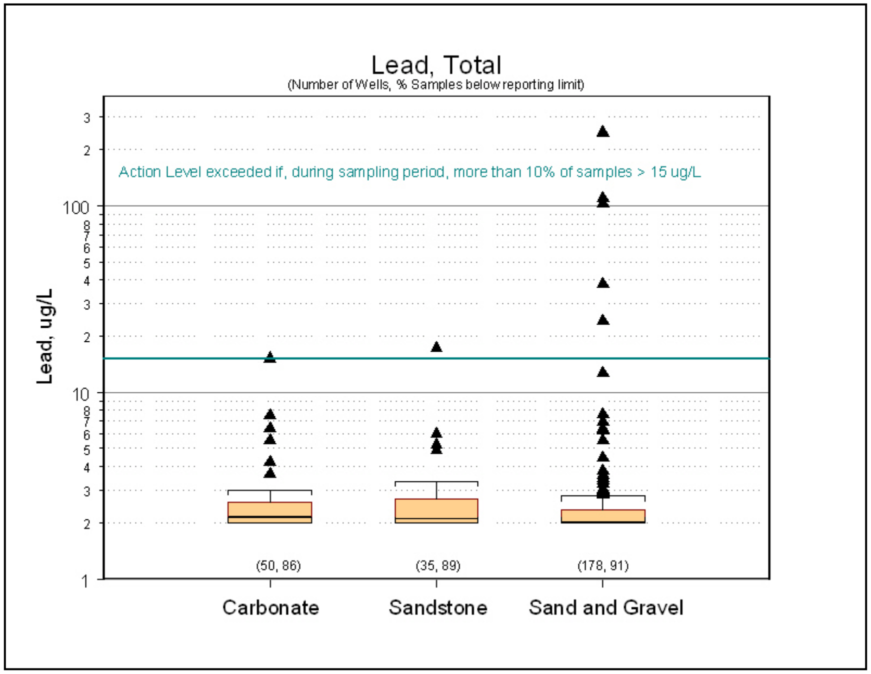


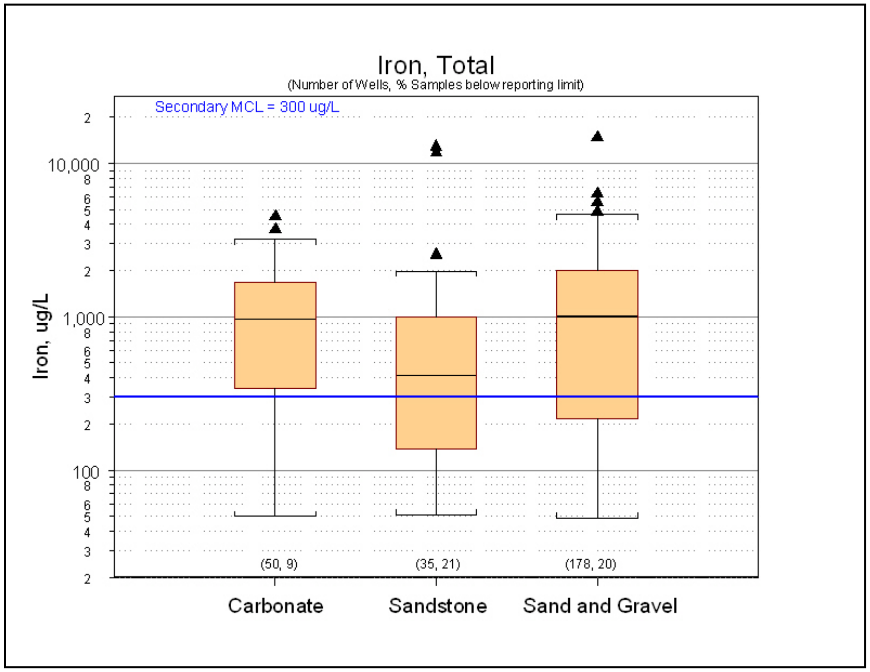

Bromide, Total
(Number of Wells, % Samples below reporting limit)
Bromide, ug/L
1,000
100
10
(50, 21)
(35, 18)
(178, 11)
Carbonate
Sandstone
Sand and Gravel

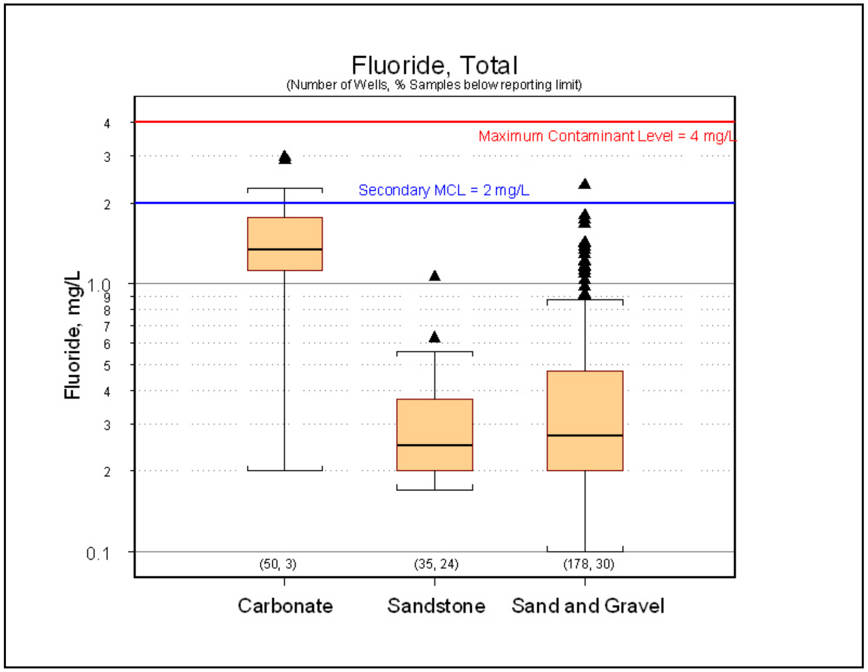

Cadmium, Total
(Number of Wells, % Samples below reporting limit)
Maximum Contaminant Level = 5 ug/L
Cadmium, ug/L
1.0
0.1
(50, 98)
(35, 99)
(178, 99)
Carbonate
Sandstone
Sand and Gravel

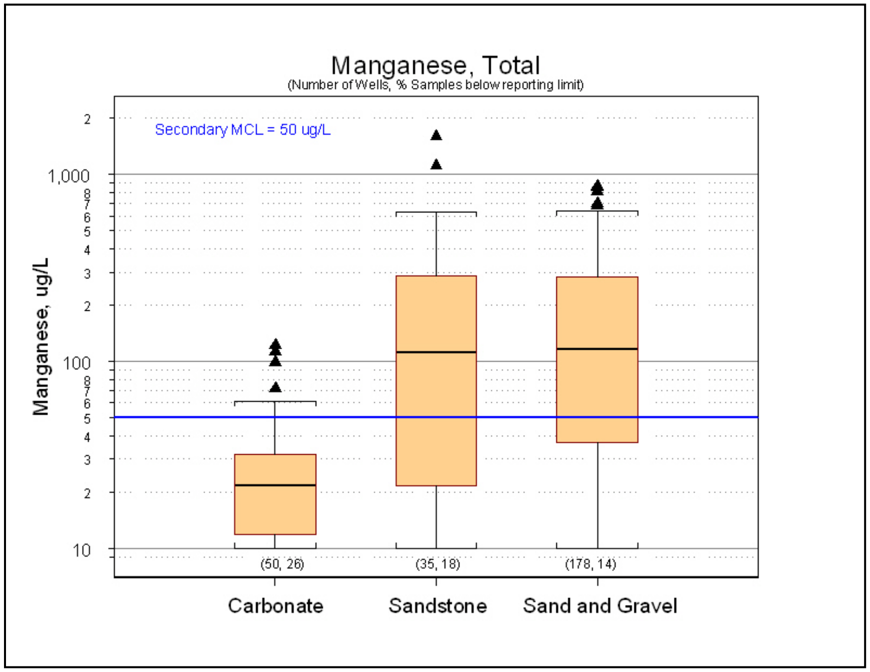

Chromium, Total
(Number of Wells, % Samples below reporting limit)
Maximum Contaminant Level = 100 ug/L
Chromium, ug/L
10
1
(50, 98)
(35, 100)
(178, 99)
Carbonate
Sandstone
Sand and Gravel

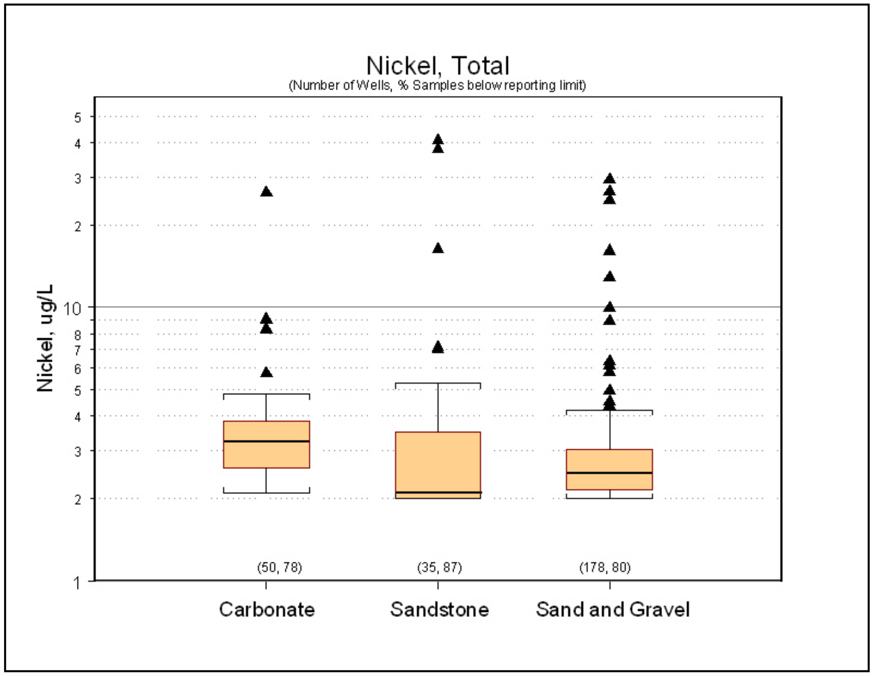

Copper, Total
(Number of Wells, % Samples below reporting limit)
Action Level exceeded if, during sampling period, more than 10% of samples > 1300 ug/L
Copper, ug/L
100
10
1
(50, 96)
(35, 98)
(178, 97)
Carbonate
Sandstone
Sand and Gravel

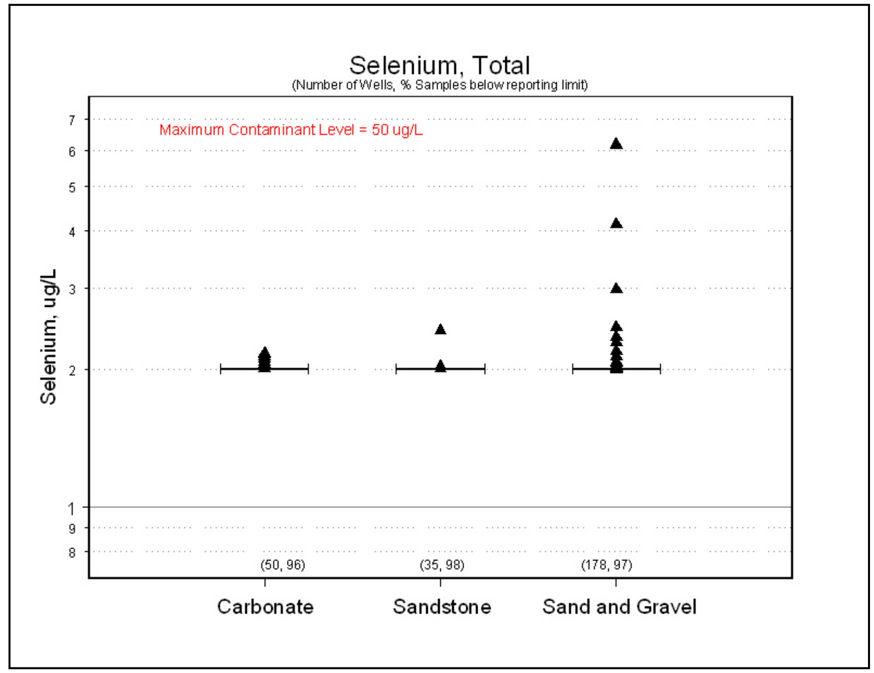

Lead, Total
(Number of Wells, % Samples below reporting limit)
Action Level exceeded if, during sampling period, more than 10% of samples > 15 ug/L
Lead, ug/L
(50, 86)
(35, 89)
(178, 91)
Carbonate
Sandstone
Sand and Gravel

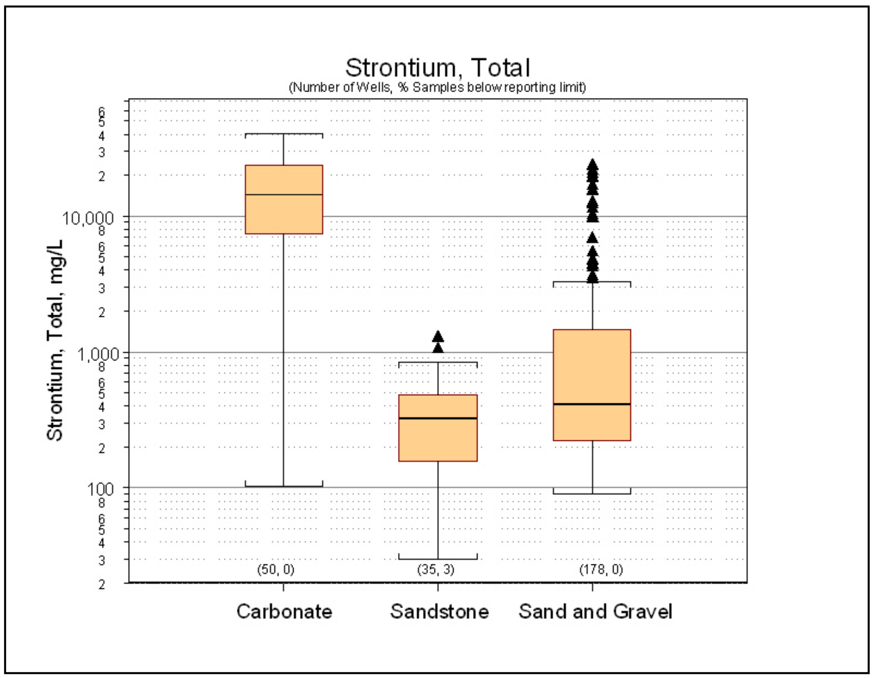

Iron, Total
(Number of Wells, % Samples below reporting limit)
Secondary MCL = 300 ug/L
Iron, ug/L
(50, 9)
(35, 21)
(178, 20)
Carbonate
Sandstone
Sand and Gravel

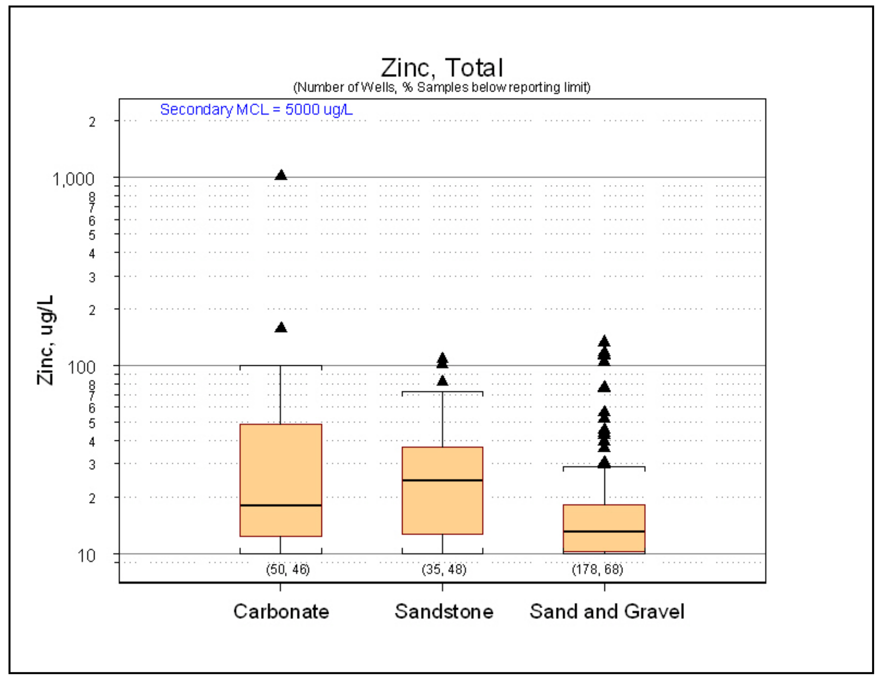

Fluoride, Total
(Number of Wells, % Samples below reporting limit)
Maximum Contaminant Level = 4 mg/L
Secondary MCL = 2 mg/L
Fluoride, mg/L
(50, 3)
(35, 24)
(178, 30)
Carbonate
Sandstone
Sand and Gravel


Manganese, Total
(Number of Wells, % Samples below reporting limit)
Secondary MCL = 50 ug/L
Manganese, ug/L
(50, 26)
(35, 18)
(178, 14)
Carbonate
Sandstone
Sand and Gravel

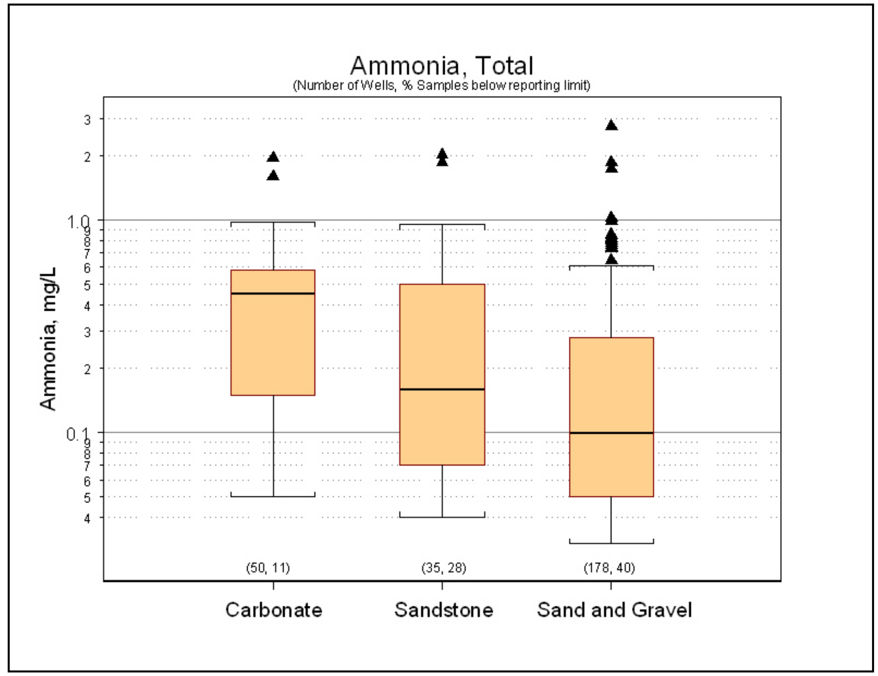

Nickel, Total
(Number of Wells, % Samples below reporting limit)
Nickel, ug/L
(50, 78)
(35, 87)
(178, 80)
Carbonate
Sandstone
Sand and Gravel

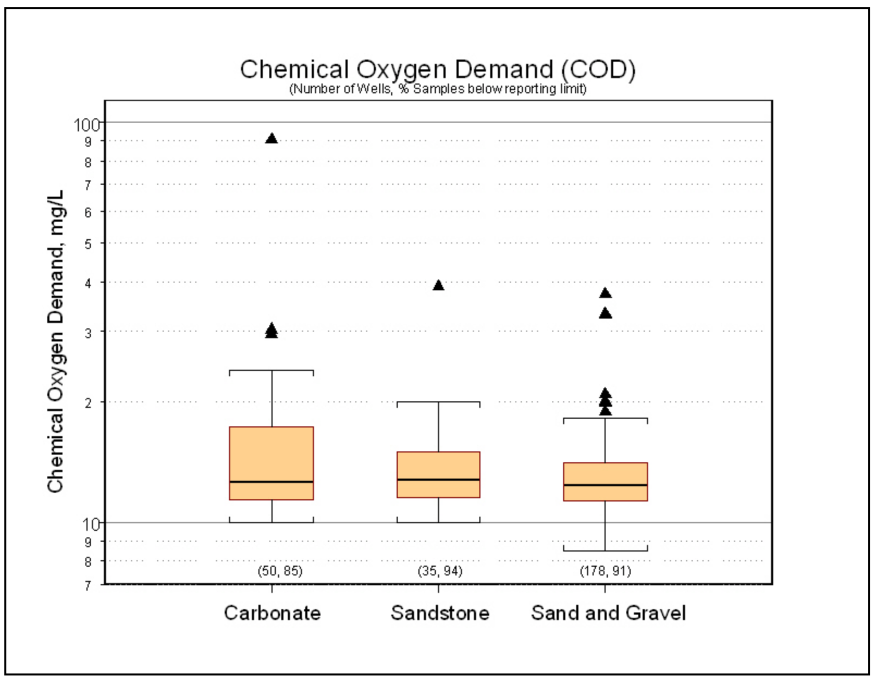

Selenium, Total
(Number of Wells, % Samples below reporting limit)
Maximum Contaminant Level = 50 ug/L
Selenium, ug/L
(50, 96)
(35, 98)
(178, 97)
Carbonate
Sandstone
Sand and Gravel

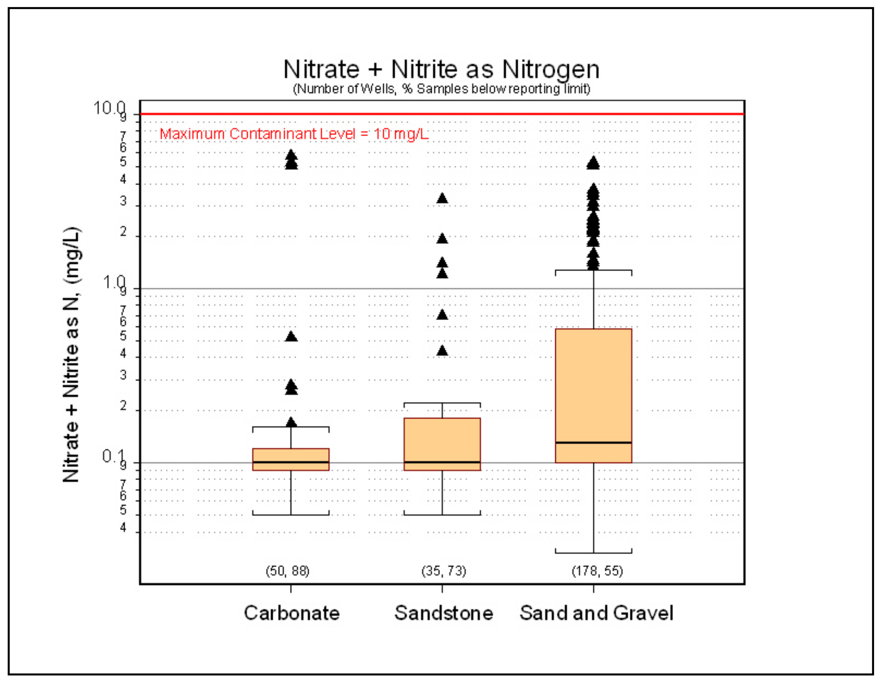

Strontium, Total
(Number of Wells, % Samples below reporting limit)
Strontium, Total, mg/L
(50, 0)
(35, 3)
(178, 0)
Carbonate
Sandstone
Sand and Gravel

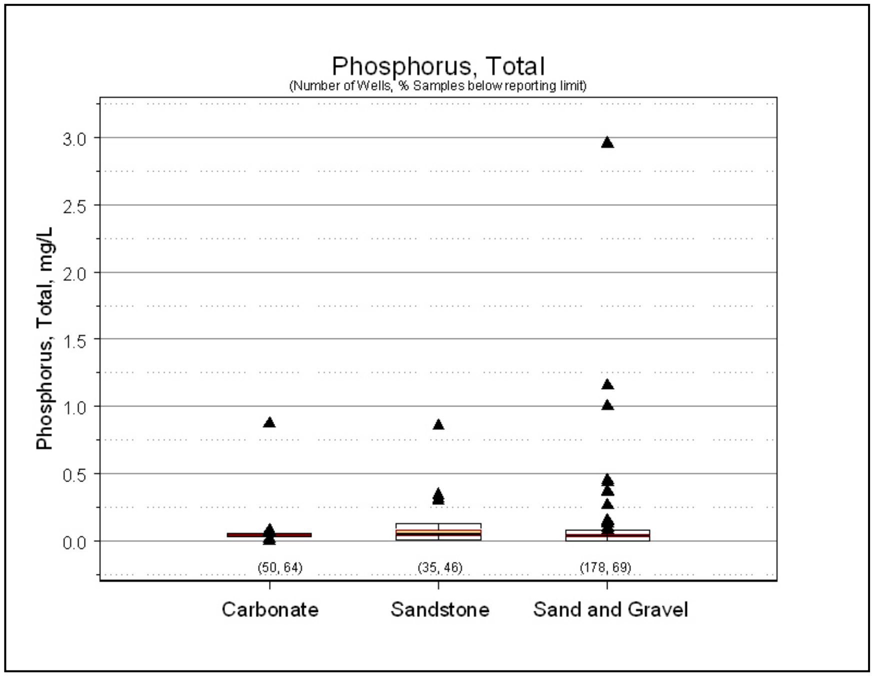

Zinc, Total
(Number of Wells, % Samples below reporting limit)
Secondary MCL = 5000 ug/L
Zinc, ug/L
(50, 46)
(35, 48)
(178, 68)
Carbonate
Sandstone
Sand and Gravel

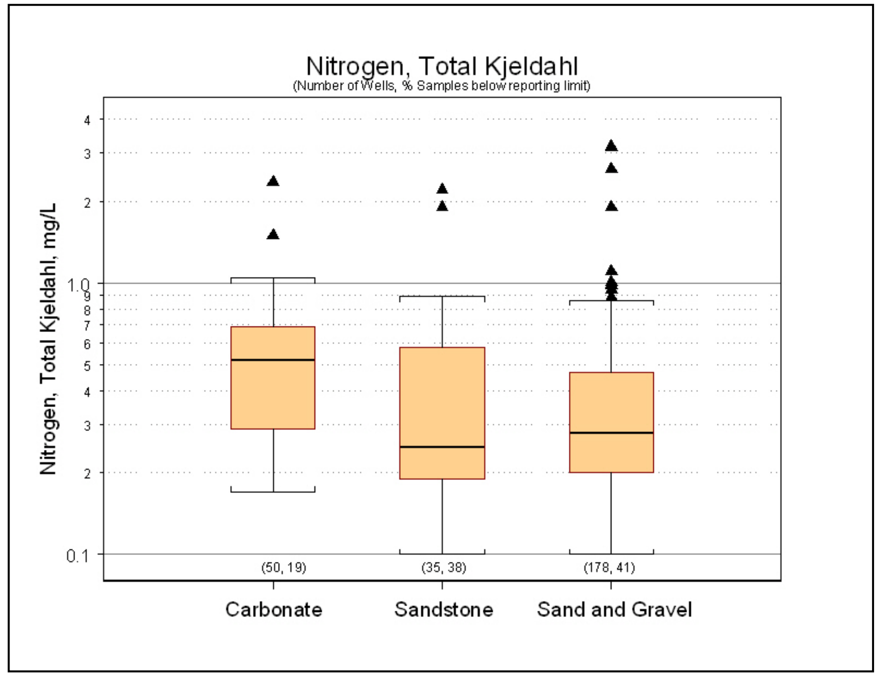
Nutrients

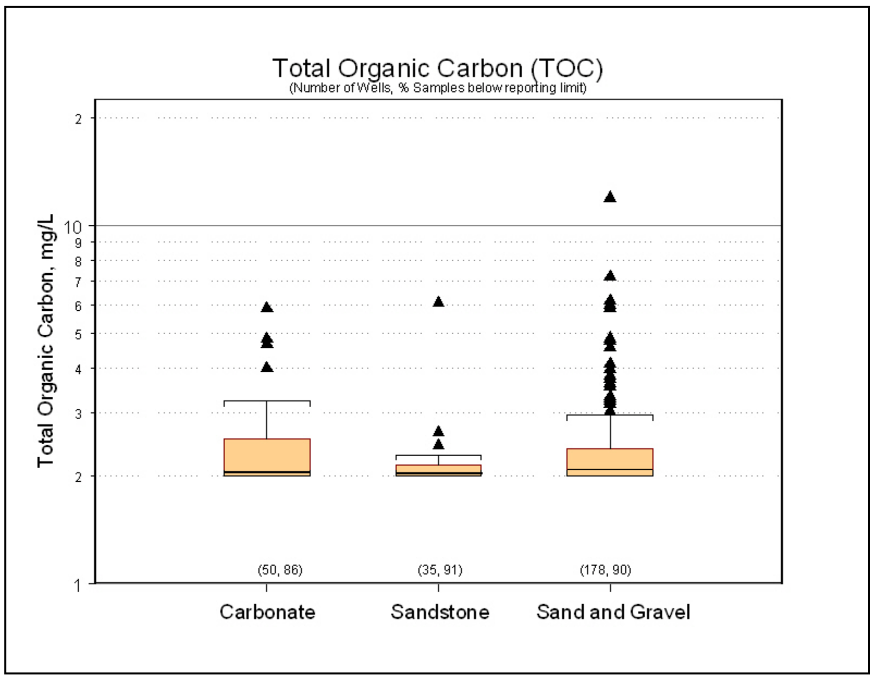

Ammonia, Total
(Number of Wells, % Samples below reporting limit)
Ammonia, mg/L
(50, 11)
(35, 28)
(178, 40)
Carbonate
Sandstone
Sand and Gravel


Chemical Oxygen Demand (COD)
(Number of Wells, % Samples below reporting limit)
Chemical Oxygen Demand, mg/L
(50, 85)
(35, 94)
(178, 91)
Carbonate
Sandstone
Sand and Gravel


Nitrate + Nitrite as Nitrogen
(Number of Wells, % Samples below reporting limit)
Maximum Contaminant Level = 10 mg/L
Nitrate + Nitrite as N, (mg/L)
(50, 88)
(35, 73)
(178, 55)
Carbonate
Sandstone
Sand and Gravel


Phosphorus, Total
(Number of Wells, % Samples below reporting limit)
Phosphorus, Total, mg/L
3.0
2.5
2.0
1.5
1.0
0.5
0.0
(50, 64)
(35, 46)
(178, 69)
Carbonate
Sandstone
Sand and Gravel


Nitrogen, Total Kjeldahl
(Number of Wells, % Samples below reporting limit)
Nitrogen, Total Kjeldahl, mg/L
1.0
0.1
(50, 19)
(35, 38)
(178, 41)
Carbonate
Sandstone
Sand and Gravel


Total Organic Carbon (TOC)
(Number of Wells, % Samples below reporting limit)
Total Organic Carbon, mg/L
10
1
(50, 86)
(35, 91)
(178, 90)
Carbonate
Sandstone
Sand and Gravel